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MODELING NONPOINT POLLUTION FROM THE LAND SURFACE

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MODELING NONPOINT POLLUTION FROM THE LAND SURFACE

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ABSTRACT

Development and initial testing of a mathematical model to continuously simulate pollutant contributions to stream channels from nonpoint sources is presented. The Nonpoint Source Pollutant Loading (NPS) Model is comprised of subprograms to represent the hydrologic response of a watershed, including snow accumulation and melt, and the processes of pollutant accumulation, generation, and washoff from the land surface. The hydrologic algorithms, derived from the Stanford Watershed Model and the Hydrocomp Simulation Program, have been previously tested and verified on numerous watersheds across the country. The simulation of nonpoint pollutants is based on sediment as a pollutant indicator. Daily accumulation of sediment, generation of sediment fines by raindrop impact, and transport of available sediment material by overland flow is simulated for both pervious and impervious areas. The calculated sediment washoff in each simulation time interval is multiplied by user-specified 'potency factors' (pollutant mass/sediment mass x 100 percent) that indicate the pollutant strength of the sediment for each pollutant simulated.

The NPS Model can simulate nonpoint source pollution from a maximum of five different land use categories in a single operation. In addition to runoff, water temperature, dissolved oxygen, and sediment, the NPS Model allows for simulation of up to five user-specified pollutants from each land use category. Pollutant parameters are specified separately for pervious and impervious areas within each land use and can vary with the month of the year to represent seasonal pollution problems. Thus, the methodology is sufficiently flexible to accommodate a variety of land use and land surface conditions.

Initial testing of the NPS Model was performed on three urban watersheds in Durham, North Carolina; Madison, Wisconsin; and Seattle, Washington. The hydrologic simulation results were good while the simulation of nonpoint pollutants was fair to good. Sediment, BOD, and SS were the major pollutants investigated. The use of sediment as a pollutant indicator appears to be acceptable for nonsoluble and partially soluble pollutants; however, highly soluble pollutants may not be directly related to sediment loss and may demonstrate significant deviation from simulated values. The scarcity of adequate water quality data severely hampered complete testing and verification of the NPS Model. In essence the results indicate that the Model can be calibrated to provide estimates of nonpoint pollutant loadings to stream channels. A detailed user manual is provided in Appendix A to assist potential users. Parameter definitions and guidelines for parameter evaluation and calibration are included. Limitations of the Model and recommendations

for future work and application are presented, and possible uses of the NPS Model are discussed.

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SECTION I

CONCLUSIONS

(1) The Nonpoint Source Pollutant Loading (NPS) Model can simulate land surface contributions of nonpoint pollutants from a variety of land uses. Model testing on three urban watersheds, comprised of residential, commercial, industrial, and open land, indicated good agreement between recorded and simulated hydrology and pollutant washoff.

(2) The NPS Model continuously simulates hydrologic processes, including snow accumulation and melt, and the nonpoint pollutant processes of accumulation, generation, and transport from the land surface. The Model can accommodate up to five land use categories and simulates water temperature, dissolved oxgygen, sediment, and up to five user-specified nonpoint pollutants from each land use.

(3) Review of the literature has shown that existing nonpoint pollution models do not consistently represent the physical processes of soil erosion and pollutant transport from both pervious and impervious land surfaces. The Universal Soil Loss Equation is not applicable to the continuous simulation of soil erosion processes although it has been used for this purpose. Thus, the NPS Model was developed to provide a consistent method of simulating soil erosion and nonpoint pollution transport from both pervious and impervious areas. The Model is designed for immediate application by planning agencies in the analysis of nonpoint pollution problems.

(4) The hydrologic methodology of the NPS Model has been extensively applied, tested, and verified on numerous watersheds of varying size across the country. Simulation results were good on the watersheds tested in this study, and similar accuracy can be generally expected in other areas.

(5) Sediment and sedimentlike material can be used as an indicator of the land surface contributions of many nonpoint pollutants. Thus,

specification of the pollutant strength, or potency, of sediment in conjunction with the simulation of sediment yield from pervious and impervious areas provides a workable methodology for simulating nonpoint pollution. The NPS Model algorithms are based on this concept. Although the simulated pollutants in this study were limited to sediment, biochemical oxygen demand, and suspended solids, the methodology is applicable to most insoluble and partially-soluble pollutants including many nutrient forms, heavy metals, organic matter, etc. However, highly soluble pollutants may demonstrate significant deviation from the simulated values.

(6) The NPS Model provides estimates of the total land surface loading to water bodies for various nonpoint source pollutants. Since the Model does not simulate channel processes, comparison of simulated and recorded values should be performed on watersheds less than 250 to 500 hectares (1 to 2 square miles) in order to avoid the effects of channel processes on the recorded flow and water quality. Size limit will vary with climatic, topographic, and hydrologic characteristics. Whenever channel processes appear to be significant, the output from the NPS Model should be input to a model that simulates stream processes before simulated and recorded values are compared.

(7) Due to incomplete quantitative descriptions of the processes controlling nonpoint pollution, calibration of certain Model parameters by comparing simulated and recorded values is a necessary step when applying the NPS Model to a watershed. Although all parameters can be estimated from available physical, topographic, hydrologic, and water quality information, calibration is needed to insure representation of the processes occurring on the particular watershed.

(8) The NPS Model can provide long-term continuous information on nonpoint pollution that can be used to establish the probability and frequency of occurrence of pollutant loadings under various land use configurations. Thus, when properly calibrated, the NPS Model can supplement available nonpoint pollution information and provide a tool for evaluating the water quality impact of land use and policy decisions.

SECTION II

RECOMMENDATIONS

(1) Application of the NPS Model to watersheds across the country is the primary need at this time. Although the Model has been tested on three watersheds, further application is required before it will be acceptable as a general and a reliable model. These applications will provide additional information on parameter evaluation under varying climatic, edaphic, hydrologic, and land use conditions, and may expose areas requiring further development and refinement in the simulation methodology.

(2) The application and use of the NPS Model as a tool for evaluating the impact of land use policy on the generation of nonpoint pollutants should be demonstrated. This could be done in conjunction with local planning agencies who might assist in Model application, benefit from simulation results, and have access to the NPS Model for continuing use in the planning process. Such a project would demonstrate the utility of the NPS Model in a real-world setting.

(3) To promote use of the NPS Model, user workshops and seminars should be held to acquaint potential users with the operation, application, and data needs of the Model. In addition, a central users' clearinghouse could be initiated to (a) provide assistance to users with special problems, (b) recommend possible sources of data, (c) categorize and collect parameter information on calibrated watersheds, and (d) direct future improvements in the Model as indicated by the needs and comments of the users. The availability of these services would greatly facilitate, expand, and promote the use of the NPS Model.

(4) Further research and development of the NPS Model should be directed to the following topics:

   (a) development of computer programs to further assist user application, such as: plotting and statistical analyses routines; data handing and management programs; and self-calibration and parameter optimization procedures.

(b) testing and application of the NPS Model on agricultural, construction, and silvicultural areas to examine special problems and pollutants associated with these land use activities.

(c) development of a stream simulation model to accept output from the NPS Model and perform the necessary flow and pollutant simulation for in-stream processes. Such a model would help eliminate the watershed size limitation of the NPS Model.

(d) continued research and refinement of the land surface pollutant washoff algorithms with examination of the behavior of highly soluble pollutants.

SECTION III

INTRODUCTION

It is becoming increasingly evident that the water quality goals established by the Federal Water Pollution Control Act Amendments (FWPCAA) of 1972 cannot be attained by regulation of only point source pollution. Indeed, in many areas pollutants emanating from nonpoint sources comprise the major contribution to water quality degradation. This is especially true for rural and agricultural lands. Even in urban areas, where point source pollution is frequent, the importance of nonpoint pollution in overall water quality management has been clearly demonstrated (1, 2). The U.S. Environmental Protection Agency, responsible for the administration of FWPCAA, has stated the following reasons for the control of nonpoint source pollution (3):

(1) attainment and maintenance of water quality objectives may be impossible using only the point source controls;

(2) inequity may result from imposition of point source controls only;

(3) nonpoint source controls may be the most cost-effective.

Before nonpoint sources can be adequately controlled, evaluation and prediction of their extent and origin must be performed. This report describes the development and initial testing of a tool, in the form of a mathematical model, and a methodology for the evaluation of nonpoint source pollution.

NONPOINT SOURCE POLLUTION

To fully realize the extent and nature of nonpoint source pollution, a formal definition would be helpful. However, a clear precise definition is not presently available. The FWPCAA of 1972 do not specifically define nonpoint pollutants. Section 208 requires that the responsible agencies identify those nonpoint source pollution problems of concern in the individual planning areas (4). Thus, the issue is side-stepped, and the responsibility to define this problem is passed to the states and planning agencies. As with many elusive concepts, nonpoint pollution is specified in terms of its negative, i.e., what it isn't. Literally, it is defined as pollutants that are not discharged from point sources. However, this is not entirely satisfactory since nonpoint pollution includes many small point sources (rural septic tanks, small animal feedlots, combined sewer overflows, etc.) for which effluent permits are not required under the National Pollution Discharge Elimination System (5).

In the absence of a precise definition, the EPA has provided substantial guidance for the understanding of nonpoint pollution problems by specifying various categories and sources. The categories have been enumerated as follows (6):

sediment
mineral pollutants (acid mine drainage, salinity, heavy metals)
nutrients (especially nitrogen and phosphorus compounds)
pesticides
biodegradable pollutants
thermal pollution
radioactivity
microbial pollution

The first five categories are considered to be the major types of nonpoint pollutants of immediate concern. Sediment is by far the largest pollutant in terms of total annual volume. An often quoted figure of 3.6 billion tonnes (4 billion tons) is considered to be the total annual sediment production from the land surface of the United States, 50 percent of which is estimated to reach lakes and streams (7). In addition, sediment is a carrier for many other nonpoint pollutants.

Pesticides and mineral pollutants are important because of their toxicity to various forms of plant and animal life. Nutrients accelerate the eutrophication process and biodegradable pollutants deplete the oxygen content of surface waters. Thus, all of these five categories have considerable impact on water quality. Thermal pollution and radioactivity are relatively minor nonpoint pollutants although they can be associated with silviculture and mining activities, respectively. Microbial pollution (pathogens and bacteria) can be a significant health problem produced by livestock and rural human waste disposal. However, these problems are highly individual in nature and are not well characterized or documented. Microbial pollution continues to be a major research topic.

Sources of nonpoint pollution are most often discussed in terms of the land use activities that produce the various pollutants. The major land use activities contributing to nonpoint pollution include:

urban development
agriculture
urban and rural construction
silviculture
mining

Man is obviously the benefactor from these activities, but he is also the culprit behind the generation of pollutants. The impact of these activities on water quality is indicated by the types of substances produced. Urban development contributes a wide variety of materials from all five of the major pollutant categories. The relative mixture of land uses in the urban area (residential, commerical, industrial, open space, etc.) affects the relative quantities of the individual pollutants. Agriculture, construction, and silvicultural operations produce sediment, nutrients, and pesticides as nonpoint pollutants. Mineral pollutants (dissolved salts) can be a product of agricultural activities through irrigation return flows. Mining produces mineral pollutants, such as acids, heavy metals, and dissolved salts. Although certain localized investigations (8, 9) in urban areas have not established the relationship between land use and water quality, more general studies (2, 10, 11, 12) have clearly indicated the importance of different types and concentrations of human activities on water quality. Indeed, EPA Administrator, Russell E. Train, has advocated land management techniques as a control method for nonpoint pollution (13).

General statements about the quantities of specific pollutants are difficult to make because of the inherent complexities and variability of nonpoint pollution. In addition to land use, pollutant quantities are affected by hydrologic and topographic characteristics, vegetal cover, season of the year, street cleaning, land management practices, etc. In short, anything that influences the accumulation of pollutants on the land surface or the mechanisms which transport pollutants from the land surface has a direct impact on nonpoint source pollution.

The end result of all these factors is generally presented in the literature as concentrations of various water quality pollutants measured in the runoff. Unfortunately, literature values are often sporadic or fragmentary. Differences in sampling procedures, analytical methods, and measured parameters complicate comparisons of reported data. In addition, mixed land uses in watersheds hide the effects of specific land use activities.

In spite of these problems a brief discussion of the relative magnitudes of nonpoint pollution is in order. A conventional literature review, an integral part of many reports on nonpoint pollution, will not be presented here. Several excellent reviews are available (2, 6, 12, 14, 15). Table 1 has been abstracted from various sources to provide a quantitative overview of nonpoint pollution and a comparison with typical municipal sewage. Pollutant content of precipitation is included in Table 1 to indicate the magnitude of contamination from this relatively uncontrollable source. Urban runoff is generally considered to have a BOD content similar to secondary municipal effluent, while suspended solids and coliform numbers are significantly greater than secondary effluent (10). Agricultural cropland is considered to be a major contributor of sediment and attached nutrients (6). Although the average nutrient concentrations from agricultural land in Table 1 are low to moderate, the resulting mass loading of nutrients to streams can be large due to the high volume of runoff and the large acreage of agricultural land. Approximately 60 percent of the nitrogen and 42 percent of the phosphorus input to water supplies each year is attributed to agriculture (16). Unmanaged forest and rangeland generally produce low pollutant concentrations; they are often considered to be natural, or background conditions due to low human and animal populations and relatively undisturbed acreage. Animal feedlots produce high concentrations of nutrients and oxygen demanding material. Construction areas produce extreme sediment loads, with attached nutrients, pesticides, and other pollutants, during the period when land surface disturbances are occurring and the land is subject to erosive forces. Both animal feedlots and construction areas are localized problems that produce intense nonpoint pollutant loads in the specific area of concern.

Perhaps the most valid statement that can be made about nonpoint source pollution is that it is extremely variable. The ranges of pollutant concentrations in Table 1 are a partial indication of this variability. Except for irrigation return flow and ground water contributions, nonpoint pollution occurs exclusively during storm events. Pollutant concentrations vary by orders of magnitude from one watershed to another, from one storm to the next, and within a single storm event. Thus, average pollutant concentrations have very little meaning in quantifying the extent of specific nonpoint pollution problems. Total pollutant mass loading, the product of pollutant concentration and flow, is a better measure for evaluating these problems (2, 10, 12). The fact that total mass is the product of concentration and flow indicates the dual importance of water quality (pollutant concentration) and hydrologic (flow) characteristics in the proper analysis of nonpoint source pollution.

Table 1. CHARACTERISTICS OF NONPOINT POLLUTION COMPARED WITH MUNICIPAL SEWAGE[a] (mg/l)

	Total solids		Susp solids		BOD		COD		NO_3-N		Total N		Total P		
	Mean[b]	Range	Mean[b]	Range	Mean[b]	Range	Mean[b]	Range	Mean[b]	Range	Mean[b]	Range	Mean[b]	Range	Ref
Municipal sewage															
typical untreated			200	100-350	200	100-300	500	250-750			40		10		10
typical treated															
primary			80	40-120	135	70-200	330	165-500			35		7.5		10
secondary			15	10-30	25	15-45	55	25-80			30		5.0		10
General characteristics															
precipitation				11-13		12-13		9-16		0.14-1.1		1.2-1.3		.02-.04	12
forested land										0.1-1.3		0.3-1.8		.01-.11	12
agricultural															
cropland					7		80		0.4		9			.02-1.7	12
urban land															
drainage		194-8620		5-7340		12-160		85-110			3			.2-1.1	12
animal feedlot runoff						1000-11000		3100-41000		10-23		920-2100		290-360	12
Individual studies															
Kansas															
beef cattle feedlot		10000-25000				1000-11000		4000-40000				200-450[c]			12
Waynesboro, VA															
forested (site 2)				15-311				24-52				1.05-1.68[c]		0-0.33	14
Durham, N.C.															
urban															
(Bryan study)	2730	274-13800			14.5	2-232	179	40-600					.58[d]	.15-2.5[d]	68
Durham, N.C.															
urban															
(Colston study)	1440	194-8620[l]	1223	27-7340[l]			170	20-1042			0.96[c]	.1-11.6[c]	.82	.2-16	8
Cincinnati, Ohio															
urban			227	5-1200	17	1-173	111	20-610					1.1[d]	.02-7.3[d]	2
Coshocton, Ohio															
rural			313	5-2074	7	.5-23	79	30-159					1.7[d]	.25-3.3[d]	2
Seattle, WA															
urban industrial															
SS3 site	140[e]		80		19		95		0.83			2.91[f]	.32[g]		72
Seattle, WA															
urban commercial															
CBD site	303[e]		190		22		66		0.72			2.82[f]	.87[g]		72
Tulsa, OK[h]															
urban															
mixed land uses	545	199-2242	367	84-2052	11.8	8-18	85.5	42-138			.85[i]	.36-1.48[i]	1.15[j]	.54-3.49[j]	10
Madison, WI															
urban residential	280								0.60		4.55[k]		.98		71
Eastern South Dakota															
agriculture runoff															
cultivated (rain)	1241		1021				148		1.5		4.1[k]		1.05		60
cultivated (snow)	187		51				49		1.0		3.1[k]		0.44		60
pasture (snow)	150		18				69		0.9		4.2[k]		0.67		60
grassland (snow)	134		42				62		0.8		3.6[k]		0.43		

a. Data presented here are for general comparison only. Since different sampling methods, number of samples, and other procedures were used, the reader should consult the references before using the data for specific planning purposes.
b. Individual values may apply to average or median. Check cited reference for clarification.
c. Total Kjeldahl Nitrogen, mg/l N
d. Total phosphate, mg/l P
e. Suspended plus settleable solids.
f. Sum of organic, ammonia, nitrite, and nitrate as mg/l N.
g. Hydrolyzable and ortho as mg/l P.
h. Values refer to the mean and range of mean values for 15 test areas.
i. *Organic Kjeldahl nitrogen.*
j. Only soluble orthophosphate.
k. Sum of organic, ammonia, and nitrate as mg/l N.
l. Range of values reported below.

MODELING NONPOINT SOURCE POLLUTION

Because of the complex relationships and the limited field data, statistical methods of analysis are not effective in the evaluation of nonpoint pollution (17). Models based on such methods most often utilize average conditions and characteristics (land use, climate, hydrology, etc.) that cannot represent the inherent variability. Moreover, extrapolation to other geographic areas or conditions is often impossible. The only viable method of modeling nonpoint pollution is to represent in mathematical form, the physical processes that determine the accumulation/deposition, attenuation, and transport of pollutants to the aquatic environment. These water quality-related (chemical, physical, biological) and hydrologic processes that occur on the land surface and in the soil profile are continuous in nature; hence, continuous simulation is critical to their accurate representation. Although nonpoint source pollution from the land surface takes place only during storm events, the status of the land cover, soil moisture, and pollutant prior to the event is a major determinant of the volume of runoff and mass of pollutants that can reach the stream during the event. In turn, the land cover, soil moisture, and pollutant status prior to the event is the result of processes that occur between events. Street cleaning operations, urban and industrial activity, agricultural operations, vegetal growth, and pollutant transformations all critically affect the mass of pollutant that can enter the aquatic environment during a storm event. Models that simulate only single storm events cannot accurately evaluate nonpoint pollution since between event porcesses are ignored.

When modeling nonpoint source pollution, the need for continuous simulation is joined by the fact that the transport mechanisms of such pollutants are universal. Whether the pollutants originate from pervious or impervious lands, from urban or agricultural areas, or from natural or developed lands, the major transport modes of surface runoff and sediment loss are operative. (Wind transport may be significant in some areas, but its importance relative to surface runoff and sediment loss is usually small.) In this way, the simulation of nonpoint pollution is analogous to a three-layered pyramid. The basic foundation of the pyramid is the hydrology of the watershed. Without accurate simulation of runoff, modeling nonpoint pollutants is practically impossible. Indeed, models of nonpoint source pollution have been referred to as "hydrologic transport" models (18, 19) to indicate the importance of the hydrologic processes. Sediment loss simulation, the second layer of the pyramid, follows the hydrologic modeling. Although highly complex and variable in nature, sediment modeling provides the other critical transport process that must be represented. The final layer of the pyramid is the interaction or relationship of various pollutants with sediment loss and runoff, resulting in the overall transport simulation of nonpoint source pollutants.

In the past decade, the engineering and scientific community has witnessed a surge of modeling efforts related to water resource evaluation and management. Modeling of nonpoint source pollution has been a recent topic receiving considerable attention in the past five years. This attention will likely continue and intensify as a result of the impetus provided by the FWPCAA of 1972. Some of the available models that consider various forms of nonpoint pollution include:

Agricultural Chemical Transport Model, ACTMO (20)
Agricultural Runoff Management Model, ARM Model (21)
Battelle Urban Wastewater Management Model, (22)
Hydrocomp Simulation Program, HSP (23)
Pesticide Transport and Runoff Model, PTR Model (24)
Storm Water Management Model, SWMM (25, 26)
Storage, Treatment, and Overflow Model, STORM (27)
Unified Transport Model, UTM (28)
Water-Sediment-Chemical Effluent Prediction, WASCH Model (29)

This list is by no means complete. It is representative of the types of models pertinent to nonpoint pollution currently in the literature. Many of these models are comprehensive and include simulation of lakes and reservoirs, in-stream water quality, soil profile chemical and biological reactions, wastewater collection systems, financial and economic aspects, etc. The capabilities for simulating nonpoint pollution are generally divided between urban and agricultural runoff problems; few, if any, models include the capability of evaluating both. In addition, few of the models, especially those for urban areas, are based on the philosophy of continuous simulation that is critical to the modeling of nonpoint pollution. In a recent review of urban runoff models, only two out of 18 models combined the capabilities of continuous simulation and modeling urban storm runoff (30). In the agricultural realm, the importance of continuous simulation has been more consistently recognized (ACTMO, UTM, PTR Model, ARM Model, etc.) because of the obvious continuous nature of the land surface and soil profile processes that determine the extent of nonpoint pollution. Thus, in spite of the plethora of available models, sufficient gaps in model capabilities and differences in methodology warrant further research and development work. Development and refinement of models are continuing processes that parallel the understanding of the important physical processes and other advances in technology.

OBJECTIVES AND SCOPE OF THIS STUDY

The overall objectives of this study were to (1) develop a simulation model to evaluate and quantify the contribution to watercourses from nonpoint sources of pollution, and (2) develop a methodology using the above model to allow preliminary estimates of nonpoint source pollution by regional, state, and local planning agencies.

A model for nonpoint pollution requires mathematical expressions (algorithms) to represent complex physical processes. This complexity must not be reflected in the application of the Model if the Model is to be widely used. Extensive expertise in model calibration and application are not required. The Nonpoint Source Pollutant Loading (NPS) Model utilizes the state of the art in modeling nonpoint pollution in conjunction with a methodology of parameter evaluation to simplify model use.

The scope of this work is limited in the sense that only land surface contributions to nonpoint source pollution are evaluated. Subsurface and ground water pollutants are not considered, and channel processes are ignored. The NPS Model is concerned with the pollutant input to a water body from surface nonpoint pollution. Thus, the NPS Model will need to be interfaced with a stream model if overall water quality is to be evaluated in watersheds where in-stream water quality processes are significant.

The study effort was generalized to consider nonpoint pollutants from the major land use categories of urban, agriculture, forest, and construction. Although the emphasis in model testing has been on urban watersheds, the methodology is sufficiently flexible to allow application to other land uses. The water quality constituents considered in this study include temperature, dissolved oxygen (DO), sediment, biochemical oxygen demand (BOD), and suspended solids (SS). However, other constituents specified by the user can be evaluated. Since this study is concerned solely with surface pollutants, all constituents are assumed to be conservative. Efforts are underway to include in the NPS Model the capability to simulate surface nutrient contributions (nitrogen and phosphorus) from both urban and rural lands.

REPORT FORMAT

An overall description of the structure and operation of the NPS Model is provided in Section IV. The hydrologic and snowmelt processes are discussed in Sections V and VI, respectively. Detailed algorithm descriptions for these processes have been included in Appendices B and C, respectively. Since the objective of this work is the modeling of nonpoint pollution, Section VII describes the pollutant accumulation and transport processes, and their representation (algorithms) in the NPS Model. Model testing and simulation results for three urban watersheds are presented in Section VIII. Section IX enumerates possible uses of the NPS Model, its application to wastewater planning requirements of the FWPCAA (Section 208), and topics for future research and further development.

The appendices include, in addition to the hydrologic and snowmelt algorithm descriptions, the NPS Model User Manual (Appendix A), a sample input sequence (Appendix D), and the NPS Model Source Listing (Appendix E). The User Manual in Appendix A is intended to be a general handbook for use and application of the NPS Model. Model operation is described; data requirements and sources are listed; input format and output option specifications are explained; and guidelines for parameter evaluation and model calibration are provided. The potential user is advised to develop a reasonable understanding of the NPS Model parameters and their significance prior to attempting use of the NPS Model. Any model is only a tool, and a tool used improperly can do more harm than good.

SECTION IV

THE NONPOINT SOURCE POLLUTANT LOADING (NPS) MODEL

The Nonpoint Source Pollutant Loading (NPS) Model is a continuous simulation model that represents the generation of nonpoint source pollutants from the land surface. The Model continuously simulates hydrologic processes (surface and subsurface), snow accumulation and melt, sediment generation, pollutant accumulation, and pollutant transport for any selected period of record of input meteorologic data. The NPS Model is called a 'pollutant loading' model because it estimates the total transport of pollutants from the land surface to a watercourse. It does not simulate channel processes that occur after the pollutants are in the stream. Thus, to simulate in-stream water quality in large watersheds, the NPS Model must be interfaced with a stream simulation model that evaluates the impact of channel processes. The Model uses mathematical equations, or algorithms, that represent the physical processes important to nonpoint source pollution. Parameters within the equations allow the user to adjust the Model to a specific watershed. Thus, the NPS Model should be calibrated whenever it is applied to a new watershed. Calibration is the process of adjusting parameter values until a good agreement between simulated and observed data is obtained. It allows the NPS Model to better represent the peculiar characteristics of the watershed being simulated. Fortunately, most of the NPS Model parameters are specified by physical watershed characteristics and do not require calibration. However, the importance of calibration should not be underestimated; it is a critical step in applying and using the NPS Model. Guidelines and recommendations for parameter evaluation and calibration are provided in the User Manual, Appendix A.

MODEL STRUCTURE AND OPERATION

The NPS Model is composed of three major components: MAIN, LANDS, and QUAL. Figure 1 is an operational flowchart of the NPS Model

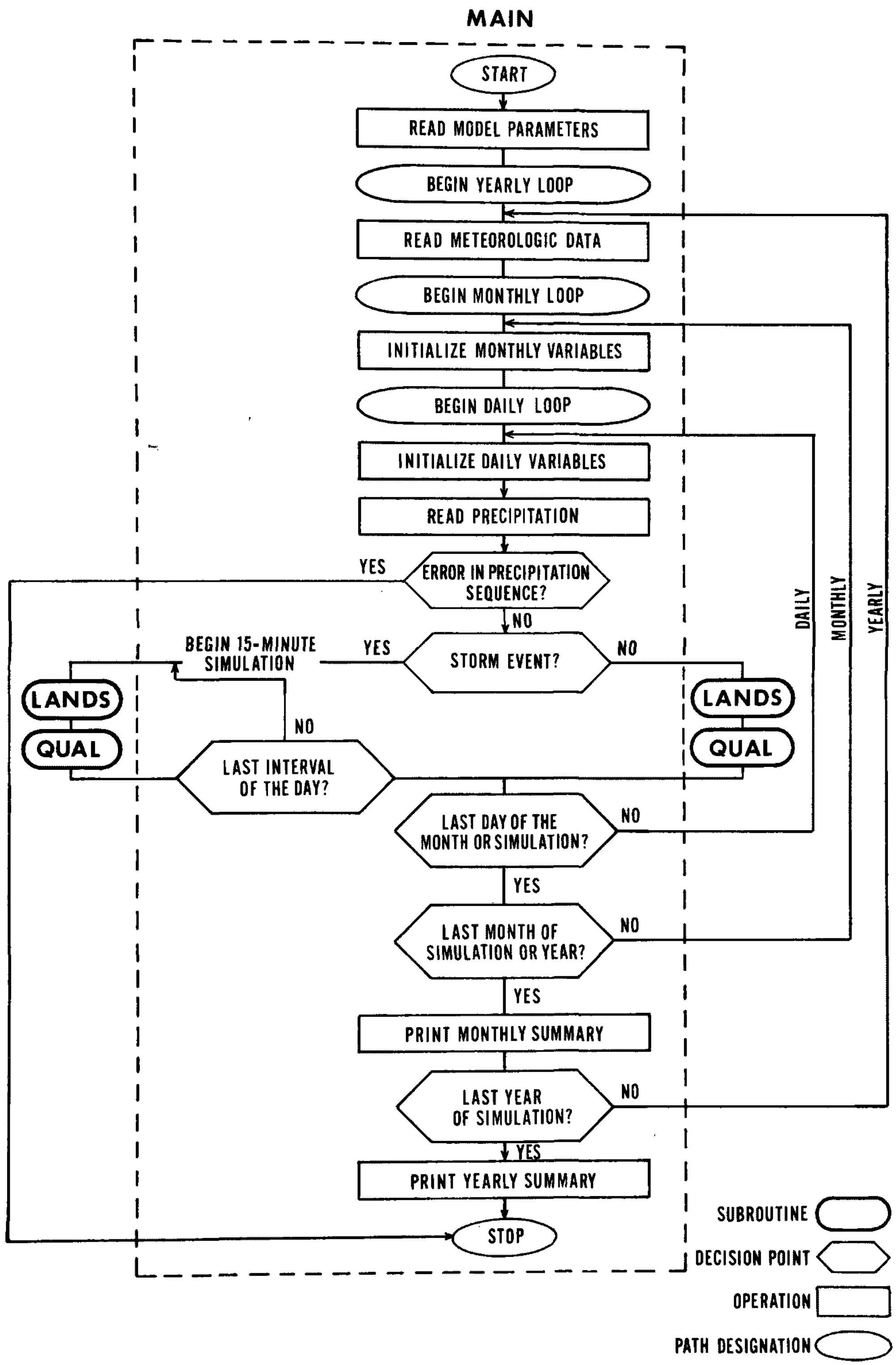

Figure 1. NPS model structure and operation

demonstrating the sequence of computation and the relationships between the components. The Model operates sequentially reading parameter values and meteorologic data, performing computations in LANDS and QUAL, providing storm event information, and printing monthly and yearly summaries as it steps through the entire simulation period. MAIN, the master or executive routine, performs the tasks contained within the dashed portion of Figure 1. It reads Model parameters and meteorologic data, initializes variables, monitors the passage of time, calls the LANDS and QUAL subprograms, and prints monthly and yearly output summaries. LANDS simulates the hydrologic response of the watershed and the processes of snow accumulation and melt. The QUAL subprogram simulates erosion processes, sediment accumulation, and sediment and pollutant washoff from the land surface. During storm events, LANDS and QUAL operate on a 15-minute time interval. LANDS provides values of runoff from pervious and impervious areas while QUAL uses the runoff values and precipitation data to simulate the erosion and pollutant washoff processes. For nonstorm periods, LANDS uses a combination of 15-minute, hourly, and daily time intervals to simulate the evapotranspiration and percolation processes that determine the soil moisture status of the watershed. Since nonpoint pollution from the land surface occurs only during storms, QUAL operates on a daily interval between storm events to estimate pollutant accumulations on the land surface that will be available for transport at the next storm event. Figure 1 indicates the individual operations of the MAIN program that occur on 15-minute, daily, monthly, and yearly intervals; these operations support the LANDS and QUAL simulation.

MODEL CAPABILITIES

The NPS Model can simulate nonpoint pollution from a maximum of five different land uses in a single simulation run. The water quality constituents simulated include water temperature, dissolved oxygen (DO), sediment, and a maximum of five user-specified constituents. All are considered to be conservative due to the short resident time on the land surface that is characteristic of nonpoint pollution. Pollutant accumulation and removal on both pervious and impervious areas is simulated separately for each land use. The Model allows monthly variations in land cover, pollutant accumulation, and pollutant removal to provide the flexibility of simulating seasonally dependent nonpoint pollution problems, such as construction, winter street salting, leaf fall, etc. Although separate land uses are considered in the QUAL subprogram, LANDS combines all pervious and impervious areas into two groups for the hydrologic simulation regardless of land use. Pervious and impervious areas are simulated separately because of the differences in hydrologic response and because of the importance of impervious areas to nonpoint pollution in the urban environment.

Output from the NPS Model is available in various forms. During storm events, flow, water temperature, dissolved oxygen, pollutant concentration, and pollutant mass removal are printed for each 15-minute interval. Storm summaries are provided at the end of each event, and monthly and yearly summaries are printed. The yearly summaries include the mean, maximum, minimum, and standard deviation of each variable. To assist interfacing with other continuous models, the NPS Model includes the option to write the 15-minute output without summaries to a separate file (or output device) for later input to the stream model. In general, the NPS Model output is provided in different forms so that the information will be usable irrespective of the type of analysis being performed. The User Manual, Appendix A, contains a full description of the output and options of the NPS Model.

SECTION V

HYDROLOGIC PROCESS SIMULATION

Since the hydrologic behavior of a watershed is a major determinant of the extent of nonpoint source pollution, an understanding of hydrologic processes is basic to the simulation of such pollutants. This section will describe briefly the hydrologic processes simulated in the NPS Model with particular emphasis on those mechanisms of importance for nonpoint pollution. Hydrologic model parameters will be defined and discussed in order to provide a sound basis for use and application of the NPS Model.

THE HYDROLOGIC CYCLE

The science of hydrology deals with the overall occurrence and distribution of water on land and in the atmosphere. The central feature of hydrology is the hydrologic cycle, which can be defined as follows:

> The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration. Also called water cycle (31).

Figure 2 schematically portrays the processes and interactions that comprise the hydrologic cycle. Entering the cycle in the precipitation phase, interception by forests or crops, overland flow across the land surface, infiltration through the soil profile, and movement through rivers and streams are all possible components in the cycle. Evaporation from water bodies and evapotranspiration from vegetation directly returns moisture to the atmosphere. Then condensation of atmospheric moisture will result in precipitation returning to the land surface to begin another cycle. The streamflow resulting from a watershed is the end product of the variable time and areal distribution of precipitation, evapotranspiration, soil moisture conditions, and physical land characteristics.

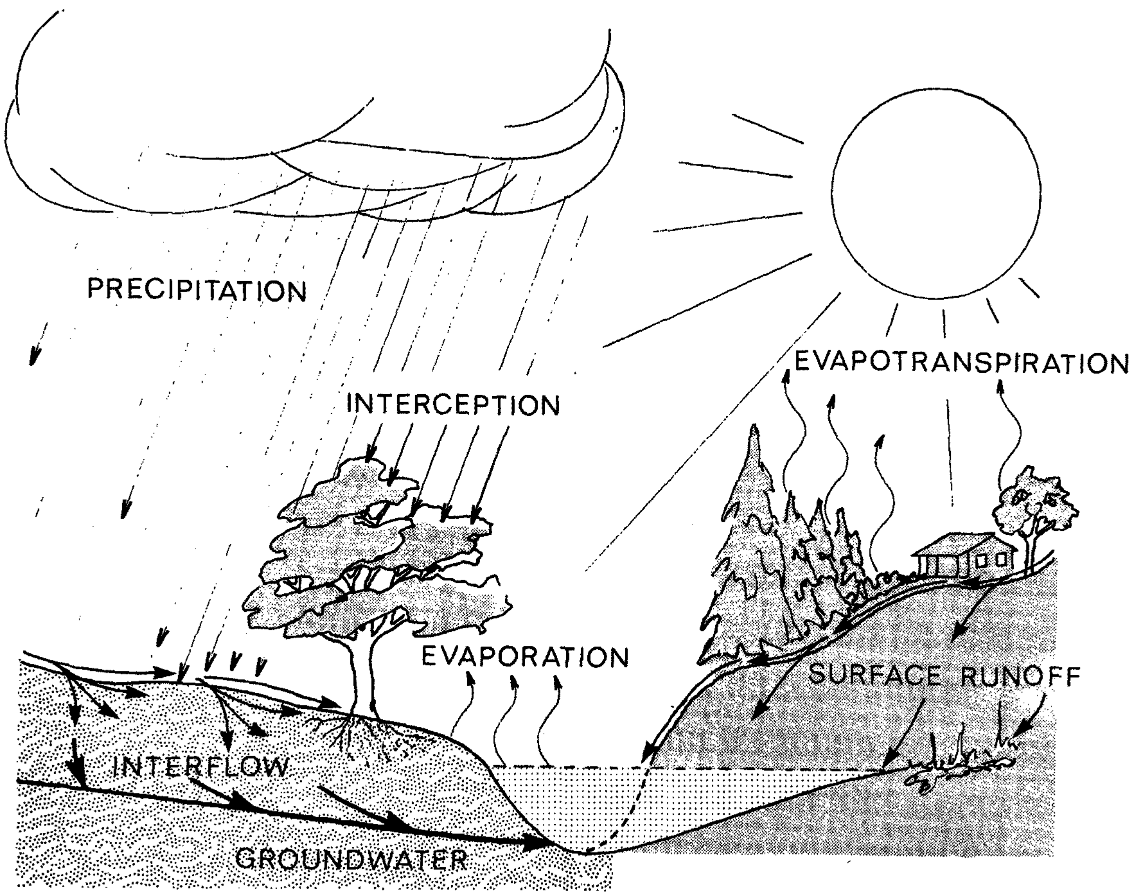

Figure 2. The hydrologic cycle

SIMULATION METHODOLOGY

The task of simulating the complex hydrologic processes described above is performed in the NPS Model by the LANDS subprogram. LANDS simulates the hydrologic response of the watershed to inputs of precipitation and evaporation. If snowmelt simulation (described below) is to be performed, additional meteorologic data is required. LANDS continuously simulates runoff through a set of mathematical functions derived from theoretical and empirical evidence. It is basically a moisture accounting procedure for water in each major component of the hydrologic cycle. Parameters within the functions are used to characterize the land surface and soil profile characteristics of the watershed. These parameters can be determined for a watershed from soil information, topographic characteristics, meteorologic data, and comparision of simulated and recorded streamflow.

A flowchart of the LANDS subprogram is shown in Figure 3. The mathematical foundation of LANDS was originally derived from the Stanford Watershed Model (32) and has been presented, with minor variations, in subsequent publications (5, 6). The LANDS algorithms are presented in Appendix B. The major parameters of the LANDS subprogram are defined in Table 2 and in the User Manual (Appendix A). These parameters are essentially identical to those in the corresponding subprogram of the ARM Model (21) and in Hydrocomp Simulation Programming, HSP (23). The only exceptions are the parameters pertaining to the simulation of overland flow from impervious areas, i.e., LI, SSI, and NNI. This modification will be described below.

The LANDS subprogram operates continuously on a 15-minute interval throughout the simulation period. Daily potential evapotranspiration and precipitation for 15-minute or hourly intervals are required inputs. If snowmelt simulation is not performed, precipitation first encounters the interception function. Interception is a storage function dependent on vegetation and land cover. In many areas interception capacity will vary with the season of the year. When interception storage is filled, any remaining precipitation is added to the moisture supply of the infiltration function, which performs the basic division of available moisture into surface detention, interflow detention, and infiltration. Surface detention includes overland flow and an increment to upper zone soil moisture storage. Interflow detention is a delay mechanism controlling the release of interflow to the stream. Infiltration and percolation from the upper zone provide the means by which moisture reaches lower zone storage. From lower zone storage, moisture moves to active ground water storage from which the ground water component of streamflow is derived.

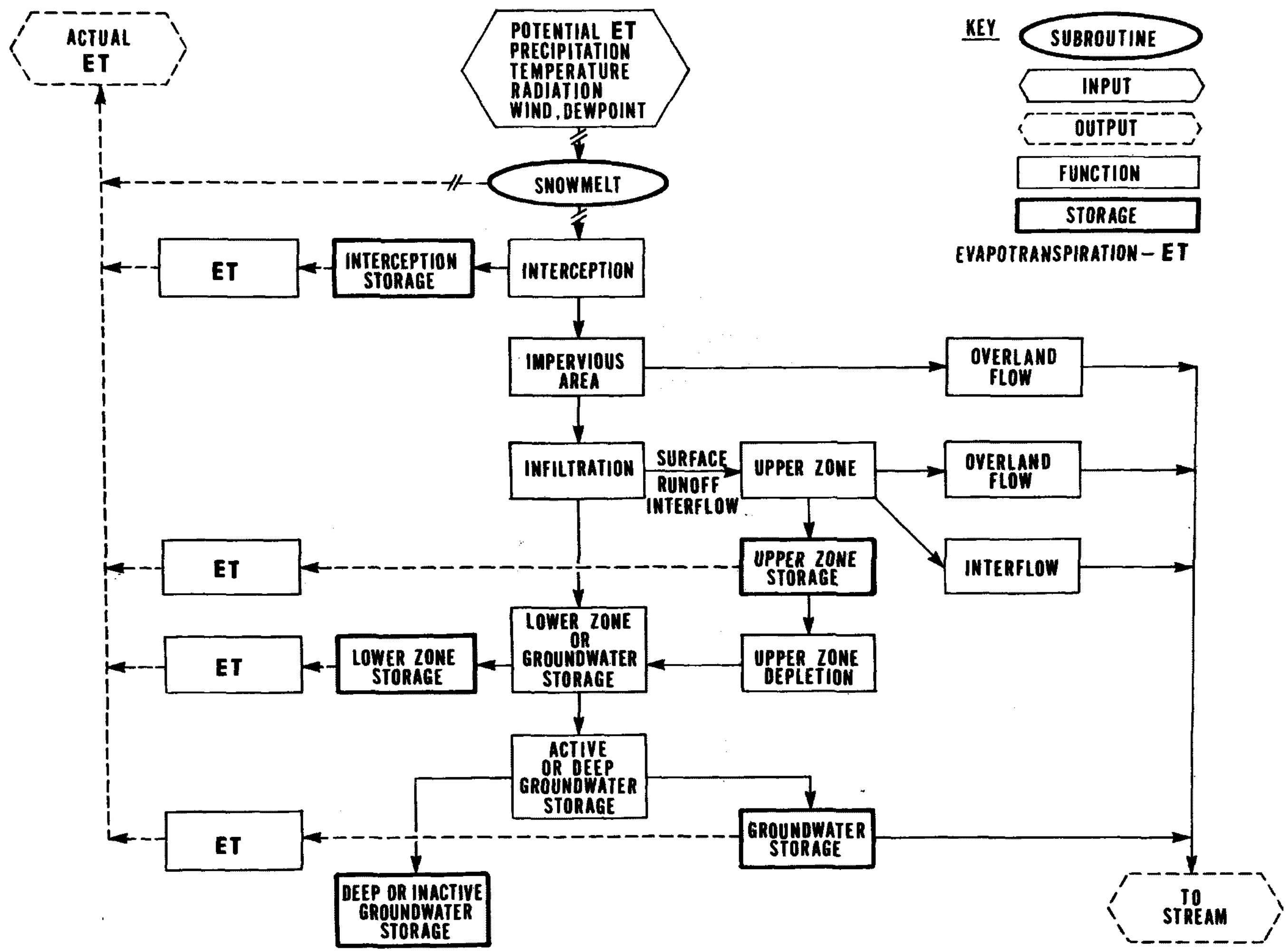

Figure 3. LANDS simulation

Table 2. HYDROLOGIC MODEL (LANDS) PARAMETERS

EPXM	The interception storage parameter, related to vegetal cover density.
UZSN	The nominal upper zone soil moisture storage parameter.
LZSN	The nominal lower zone soil moisture storage parameter.
K3	Index to actual evaporation (a function of vegetal cover).
K1	The precipitation adjustment factor.
PETMUL	The potential evapotranspiration adjustment factor.
K24L	The fraction of groundwater recharge that percolates to deep groundwater.
INFIL	A function of soil characteristics defining the infiltration characteristics of the watershed.
INTER	Defines the interflow characteristics of the watershed.
AREA	The area of the watershed.
L, LI	Length of overland flow plane (pervious and impervious).
SS, SSI	Average overland flow slope (pervious and impervious).
NN, NNI	Manning's "n" for overland flow (pervious and impervious).
IRC, KK24	The interflow and groundwater recession parameters.

Other than streamflow and losses to inactive ground water, evapotranspiration is the only remaining component in the moisture balance performed in LANDS. Evapotranspiration occurs at different rates from each of the various moisture storages shown in Figure 3. Daily potential evapotranspiration values are input and transformed to hourly values by an empirical diurnal variation. Actual evapotranspiration is calculated on an hourly basis from interception, upper zone, and lower zone storages, and on a daily basis from ground water storage. From interception storage, evapotranspiration occurs at the potential rate. Any remaining potential is satisfied initially from the upper zone and then from the lower zone, depending on existing moisture conditions.

OVERLAND FLOW SIMULATION

The process of overland flow is treated separately to emphasize its importance in the simulation of nonpoint source pollutants. Since the NPS Model is concerned solely with the surface washoff of pollutants, overland flow from pervious and impervious areas is the key transport mechanism to be simulated. The contributions from pervious and impervious areas are simulated separately but in an analogous fashion. Separate parameters describing the pervious and impervious overland flow planes (length, slope, roughness) are required for the NPS Model.

As described above, the infiltration function assigns a fraction of the incoming moisture to surface detention, which in turn is divided into upper zone soil moisture storage and overland flow. This division is performed for pervious areas in each simulation interval. The fraction of overland flow which will reach the stream channel in any interval is determined by the characteristics of the pervious overland flow plane and the routing procedure (described in Appendix B). The fraction of overland flow that does not reach the stream is available for infiltration in subsequent time intervals. This is the interaction between the infiltration and overland flow mechanisms on pervious lands.

For impervious areas, infiltration does not occur. The overland flow component is determined as the fraction of incoming rainfall that occurs on impervious areas directly connected to the stream channel. As with pervious flow, a fraction of the impervious flow component reaches the stream during the current time interval. However, the water that does not reach the stream remains on the impervious overland flow plane and is added to the incoming rainfall in the subsequent time interval. Thus, the distinction between pervious and impervious overland flow is that all rainfall that occurs on the impervious overland flow plane will eventually reach the stream channel as overland flow, whereas delayed infiltration is possible on the pervious overland flow plane.

CONCLUSION

As mentioned above, Appendix B presents the mathematical formulations of the hydrologic processes shown as functions in Figure 3. A thorough understanding of this material and the parameters described in Table 2 is necessary for a successful calibration and application of the NPS Model. This methodology for hydrologic simulation has been successfully applied to hundreds of watersheds in the U.S. and abroad. Modifications of the algorithms have been employed in the National Weather Service River Forecast System (33), the Kentucky Watershed Model (34), and the Georgia Tech Watershed Simulation Model (35). The User Manual in Appendix A provides guidelines for parameter evaluation and calibration based on past experience.

SECTION VI

SNOW ACCUMULATION AND MELT SIMULATION

In the simulation of water quality processes, the mechanisms of snow accumulation and melt are often neglected. The stated reasons for this omission generally pertain to an assumed minor influence on water quality, the extensive data requirements, and the extreme complexity of the component processes. Obviously, in the southern latitudes of the United States and at many coastal locations, snow accumulation during winter months is often negligible. However, considering its location in a temperate climatic zone, over 50 percent of the continental United States experiences significant snow accumulation. In many areas streamflow contributions from melting snow continue through the spring and early summer. For many urban areas, water supply during the critical summer period is entirely a function of the extent of snow accumulation during the previous winter. Section III stressed the importance of continuous simulation in the modeling of nonpoint source pollutants. Snow accumulation and melt is a major component in continuous hydrologic simulation, and an important part of any hydrologic model that is to provide a basis for the simulation of water quality processes.

PHYSICAL PROCESS DESCRIPTION

Snow accumulation and melt are separate but often concurrent mechanisms. The initial snow accumulation is largely a function of air (and atmospheric) temperature at the time of precipitation; whereas, snowmelt is an energy transfer process in the form of heat between the snowpack and its environment. Eighty cal/cm^2 of heat must be supplied to obtain one centimeter of water from a snowpack at 0 °C (203 cal/cm^2 or 750 Btu/ft^2 for one inch of melt at 32 °F). This heat or energy requirement is derived from the following sources:

(1) solar (shortwave) radiation
(2) terrestrial (longwave) radiation
(3) convective and advective transfer of sensible heat from overlying air
(4) condensation of water vapor from the air
(5) heat conduction from soil and surroundings
(6) heat content of precipitation

The complexity of the snowmelt process is due to the many factors that influence the contributions from each of the above energy sources. Figure 4 conceptually indicates the factors and processes involved in snow accumulation and melt on a watershed. The combination of precipitation and near or below freezing temperatures results in the initial accumulation of the snowpack. Although relative humidity and air pressure influence the form of precipitation, temperature is the major determining factor in the rain/snow division. The rain/snow division is important to the hydrologic response of the watershed. Precipitation in the form of rain can become surface runoff immediately and will contain sufficient heat energy to melt a portion of the snowpack. On the other hand, precipitation in the form of snow will augment the snowpack and is more likely to contribute to soil moisture, ground water, and subsurface flow as the snowpack melts. Just as the snow begins to accumulate, the major melt processes are initiated. Both solar (shortwave) radiation and terrestrial (longwave) radiation are contributors to the snowmelt process, although solar radiation provides the major radiation melt component. The effective energy transfer to the snowpack from solar radiation is modified by the albedo, or reflectivity, of the snow surface and the forest canopy in watersheds with forested land. Terrestrial radiation exchange occurs between the atmosphere, clouds, trees, buildings, and even the snowpack itself. Generally, solar radiation dominates the net radiation exchange during daylight hours resulting in a heat gain to the snowpack. Terrestrial radiation continues during the night causing a net heat loss from the snowpack during the dark hours. The radiation balance, in addition to the other heat exchange processes, allows melting of the pack during the day and a refreezing during the night.

When air temperatures are above freezing, convective and advective heat transfer to the snowpack produces another melt component. Condensation of water vapor on the snowpack from the surrounding air and the opposing mechanism of snow evaporation from the pack, respectively, add and subtract a component in the snowpack heat balance. Wind movement is a significant factor in all of these processes; its effect on heat transfer is readily acknowledged by anyone who has experienced a chilling northeaster. Depending on climatic conditions the condensation and convection processes can contribute to a significant portion of the snowmelt.

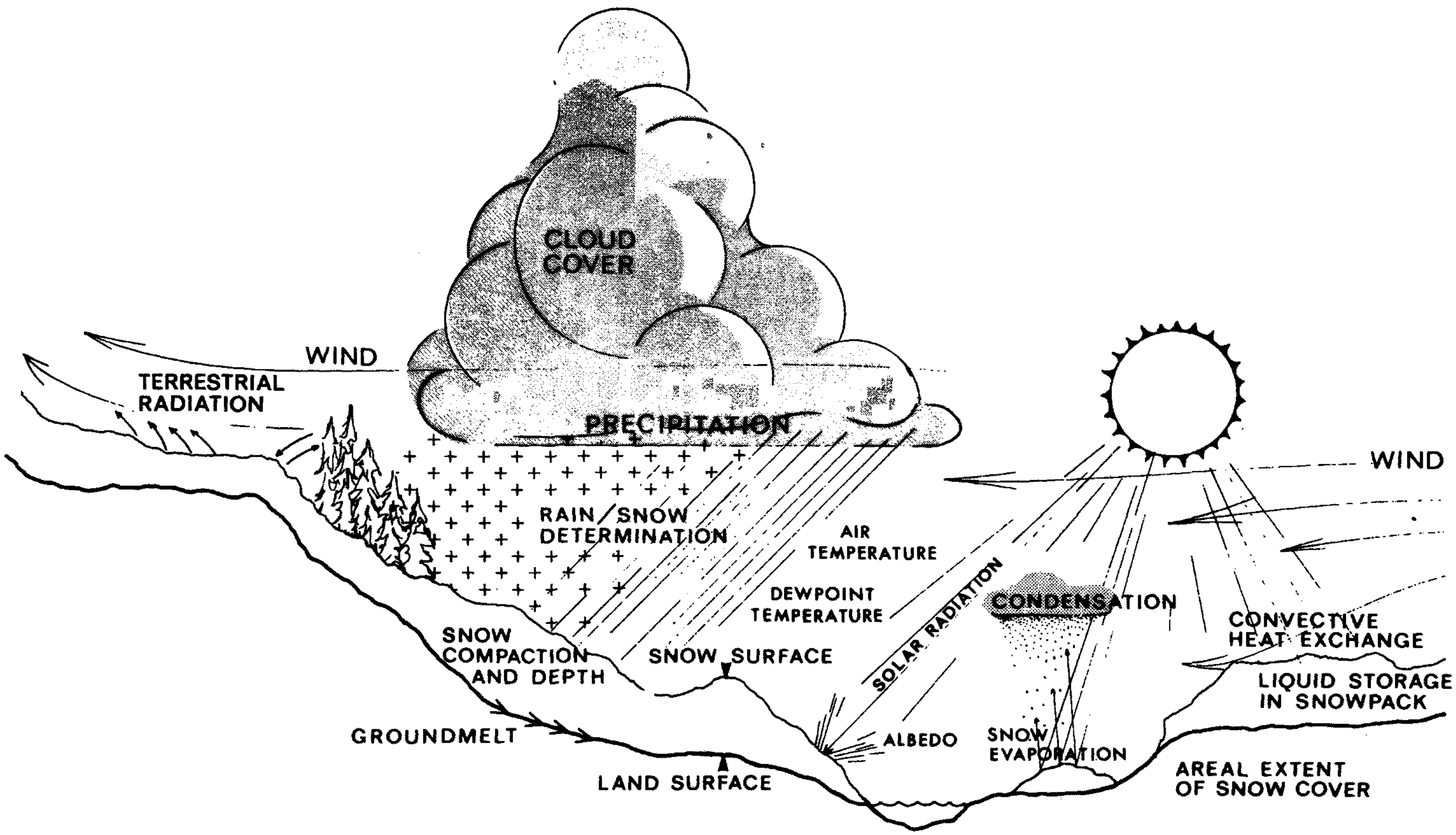

Figure 4. Snow accumulation and melt processes

The remaining melt mechanisms include the ground melt resulting from heat from the land surface and surroundings and rainmelt due to the heat input of rain impinging on the snowpack. Ground melt is due to the temperature difference between the snowpack and the land surface and subsurface. Areas that experience relatively light snowfall and low temperatures will have a small ground melt component due to the insulating effects of frost and frozen ground conditions. On the other hand, ground melt can be significant in areas with rapid accumulation and deep snowpacks. Urban areas with heat input from roads, buildings, and underground utilities, and special geologic areas (hot springs, volcanoes, etc.) can cause an unusually high ground melt contribution.

Snowmelt caused by rain on a pack is usually quite small. Twenty-five millimeters (1 inch) of rainfall at 10 °C (50 °F) will produce only 3.2 millimeters (0.125 inch) of melt. However, rain often occurs at high atmospheric humidity when condensation of water vapor can take place. Condensation of 25 millimeters (1 inch) of water vapor (water equivalent) can produce 190 millimeters (7.5 inches) of melt. Thus, water vapor condensation can cause rapid snowmelt and seems to be responsible for the myth that rainfall causes rapid snowmelt.

The release of melt water from the snowpack is a function of the liquid moisture holding capacity of the snowpack and does not necessarily occur at the time of melt. The snowpack contains moisture in both frozen and liquid form; spaces between snow crystals contain water molecules. As melt occurs, more water molecules are added to the spaces in the snowpack until the moisture holding capacity is reached. Additional melt will reach the land surface and possibly result in runoff. As the snowpack increases in depth over the season, compaction of the pack results in a lower depth and a higher snow density. As density increases the moisture holding capacity of the snowpack decreases due to less pore space between snow crystals and a change in crystal structure.

Thus, the snowmelt reaching the land surface results from complex interactions between the melt components, climatic conditions, and snowpack characteristics. For the most part, the snowpack behaves like a moisture reservoir gradually releasing its storage. However, the combination of extreme climatic conditions and snowpack characteristics can lead to abnormally high liquid moisture holding capacity and sudden release of melt in relatively short time periods (36). The damage which can occur during such events emphasizes the need to further study and understand the snowmelt process.

SNOWMELT SIMULATION

The objective of snow accumulation and melt simulation is to approximate the physical processes (described above) and their interactions in order to evaluate the timing and volume of melt water released from the snowpack. The algorithms used in simulating the processes shown in Figure 4 are based on extensive work by the Corps of Engineers (37), Anderson and Crawford (38), and Anderson (39). Empirical relationships are employed when quantitative descriptions of the process are not available. An energy balance method of simulation is utilized in the NPS Model in opposition to conventional temperature index methods in general use. The energy balance method calculates the various melt components according to the specific sources of energy in the form of heat. Meteorologic data series for radiation, wind, and dewpoint are generally required in addition to air temperature. On the other hand, the temperature index method uses air temperature as the sole index for the calculation of energy exchange and resulting snowmelt. In many instances, the temperature index method has been shown to approach the accuracy of the energy balance method (39, 40), especially when the accuracy of the meteorologic data (radiation, wind, dewpoint) is questionable. Moreover, the minimal data requirements further promotes its use. However, the energy balance method is generally considered to be more reliable and accurate if reliable meteorologic data is available (38, 39, 40). The use of the additional meteorologic data series can significantly improve snowmelt prediction (41). The energy balance method provides a sound framework for incorporation of future advances in the understanding of snowmelt simulation. In addition, short-time interval simulation of these processes for nonpoint source pollution can only be attempted in this manner. For these reasons, the energy balance method was chosen for inclusion in the NPS Model.

A mathematical description of the snowmelt algorithms is presented in Appendix C. They are identical to those employed in HSP and the ARM Model and have demonstrated reasonably successful results on numerous watersheds (42, 43, 44, 45). A flowchart of the snowmelt routine is shown in Figure 5. The routine operates on an hourly basis. Meteorologic data specifies the occurrence and amount of precipitation during the hourly interval; the form of precipitation is determined as a function of air temperature and dewpoint. The individual melt components are evaluated; heat exchange calculations within the snowpack are performed; and the resulting total melt is compared with the liquid water storage within the snowpack. The end product of the calculations is the total snowmelt released from the snowpack that reaches the land surface. This water then enters the hydrologic simulation (Section V and Appendix B) to participate in the generation of runoff. Since the LANDS simulation is performed on 15-minute intervals, the hourly melt

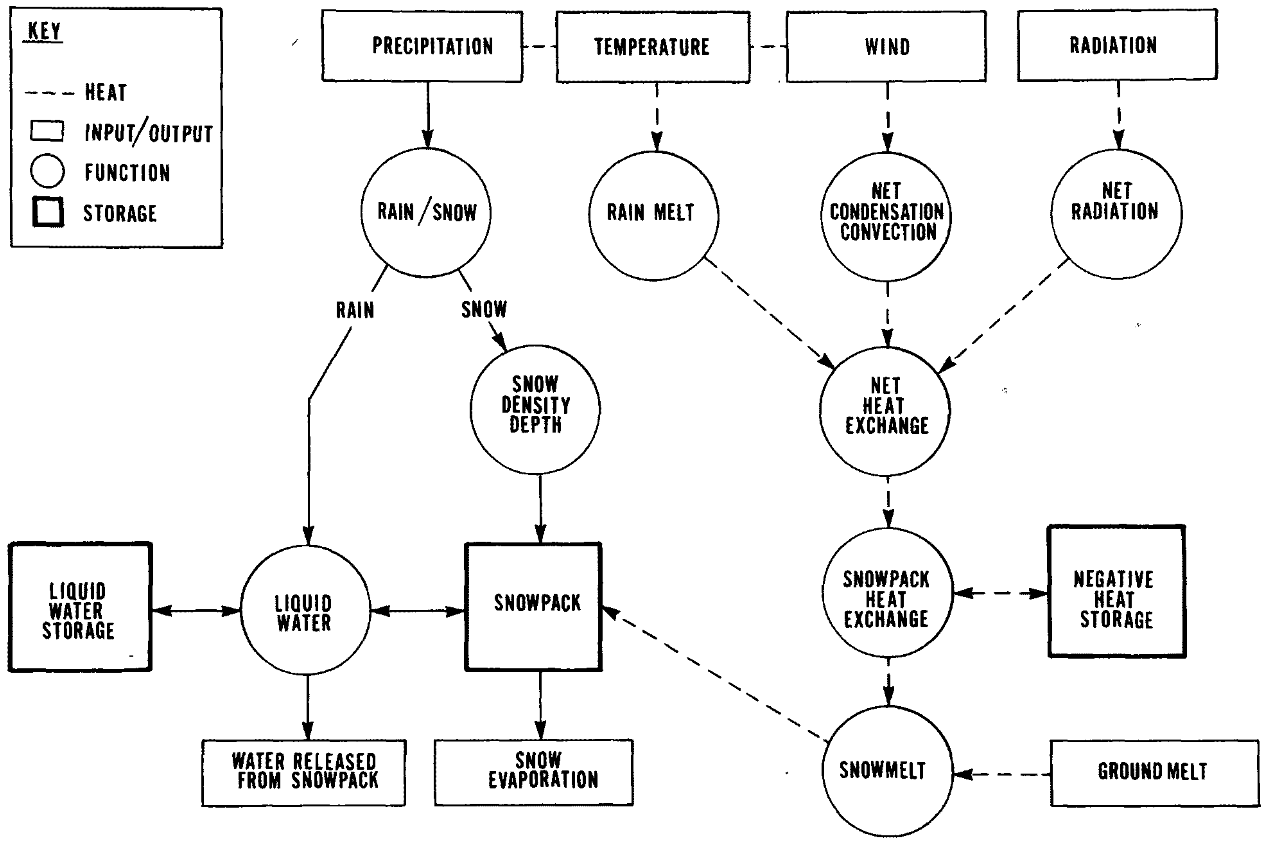

Figure 5. Snowmelt simulation

values are divided into the shorter time intervals to continue the simulation. Since the snowmelt process is much slower than the runoff process, the hourly time interval appears to be adequate.

In addition to precipitation and evaporation, the version of the snowmelt routine in the NPS Model requires the continuous data of daily max-min air temperature, daily wind movement, and daily solar radiation. Because the routine operates on an hourly basis, hourly values for each of these meteorologic values would be preferable. However, with the exception of experimental watersheds, few locations would have such detailed data. Consequently, the routine provides an empirical hourly distribution for wind movement and solar radiation. The daily max-min air temperature values are fitted to a sinusoidal distribution assuming that minimum and maximum temperatures occur during the hours beginning at 6:00 AM and 3:00 PM. Dewpoint temperature is not a required input because of the general lack of such data. It is estimated as being equal to the minimum daily temperature, a reasonable approximation in many cases (46).

Table 3 defines the input snow parameters required for operation. These parameters are used to (1) define the physical characteristics and snow conditions of the watershed, (2) adjust input meteorological data series to the specific location of the watershed, and (3) modify the theoretical melt components to field conditions. Evaluation of the snowmelt parameters is discussed in the User Manual (Appendix A). An understanding of the physical processes and the algorithm approximations is critical to the intelligent use of the snowmelt routine. Consequently, the potential user is advised to read and study the algorithm descriptions and parameter definitions prior to attempting application of the snowmelt routine.

Table 3. SNOWMELT PARAMETERS

RADCON	Parameter to adjust theoretical solar radiation melt equations to field conditions.
CCFAC	Parameter to adjust theoretical condensation and convection melt equation to field conditions.
EVAPSN	Parameter to adjust theoretical snow evaporation to field conditions.
MELEV	Mean elevation of the watershed.
ELDIF	Elevation difference between the temperature station and the midpoint of the watershed.
TSNOW	Wet-bulb air temperature below which snowfall occurs.
MPACK	Water equivalent of the snowpack required for complete coverage of the watershed.
DGM	Daily groundmelt.
WC	Maximum water content of the snow.
IDNS	Index density of new snow at 0° F.
SCF	Snow correction factor to compensate for deficiencies in the gage during snowfall.
WMUL	Wind multiplier to adjust observed daily wind values.
RMUL	Solar radiation multiplier to adjust observed daily solar radiation values.
F	Fraction of watershed with forest cover.
KUGI	Index to the extent of undergrowth in forested areas.

SECTION VII

NONPOINT POLLUTION PROCESS SIMULATION

Section III briefly discusses the nature of nonpoint pollution. Figure 6 schematically demonstrates the contributions of urban, agriculture, silviculture, and construction activities to the nonpoint pollutant load entering a water body. Mining activities are not included in Figure 6 because they are highly localized and specific in nature. The total nonpoint pollution problem is comprised of both the sources of pollutants, indicated in Figure 6, and the mechanism that moves the pollutants to the aquatic environment. In other words, the two processes of concern are:

(1) the accumulation and/or generation of pollutants, and

(2) the transport mechanisms that move pollutants to a water body.

The transport mechanisms, runoff and sediment loss, are universal whereas accumulation processes are entirely site specific. The range of activities in Figure 6 indicates the variable manner in which pollutants accumulate and become available for transport. Even within a single land use category, characteristics of the activities will vary with differences in socioeconomic levels, geographic regions, climate, etc. A methodology to evaluate nonpoint pollution must include an accurate representation of the transport mechanisms on the watershed and a flexible representation of the accumulation processes to allow adaptation to the specific site and land use.

PAST WORK

Section III notes the recent emphasis on the simulation of nonpoint pollution and lists various models that have been developed. Urban areas have received the major attention in terms of application of

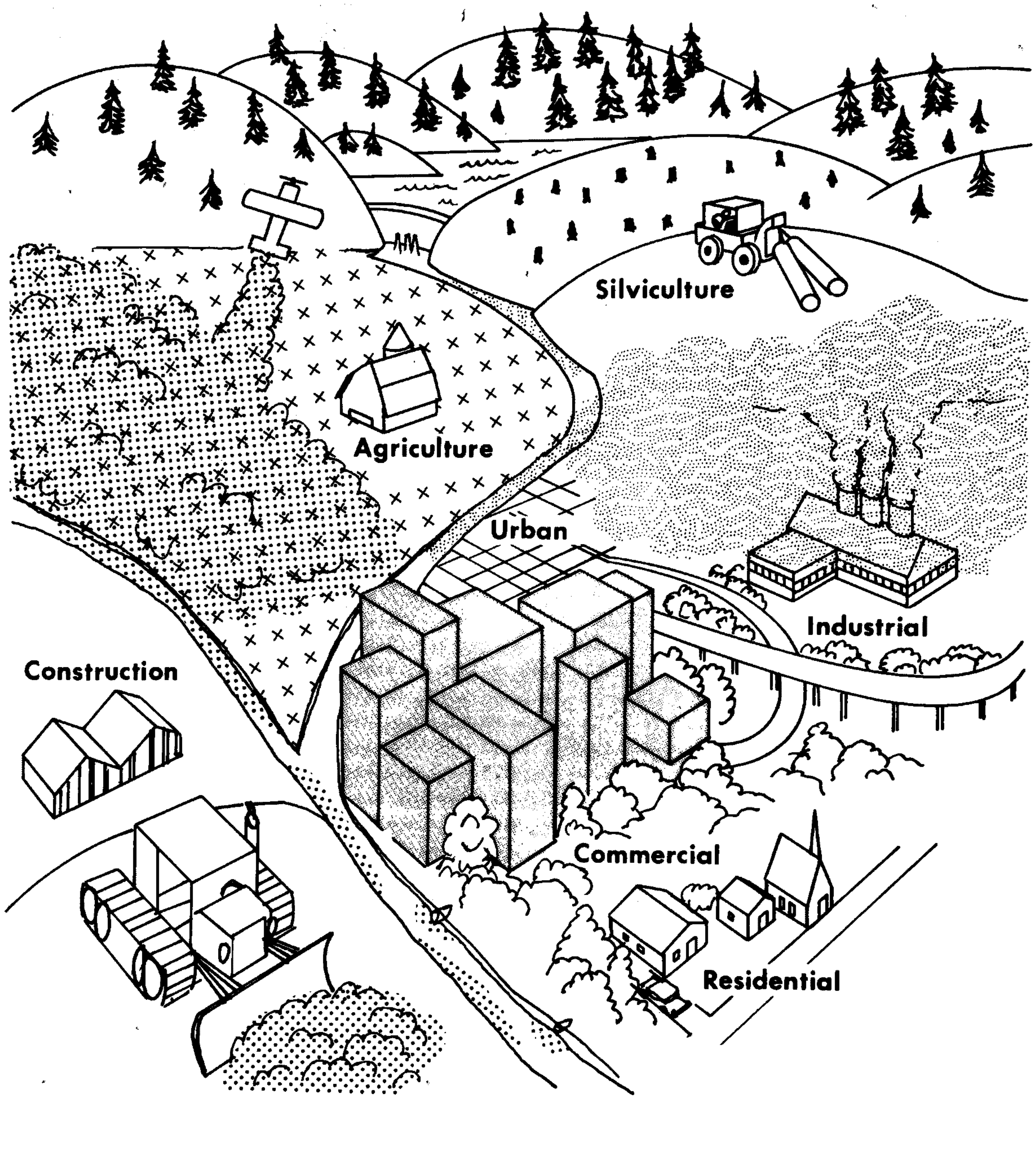

Figure 6. Sources of nonpoint pollution

available models. At the present time, nonpoint pollution models that can be applied to non-urban areas (mostly agricultural and rural land) are just beginning to emerge from the research community. The next few years will witness greater application and testing of both urban and non-urban models as a result of the impetus provided by the FWPCAA of 1972. The urban models most widely used presently include the Storm Water Management Model - SWMM (25, 26), the Storage, Treatment, and Overflow Model - STORM (27), and the water quality section of the Hydrocomp Simulation Program - HSP QUALITY (23, 47). All these models contain capabilities in addition to the simulation of nonpoint source pollutants generated from the land surface. However, only the portions related to nonpoint pollution were evaluated in this work. The methods of simulating accumulation and transport, or washoff, of nonpoint pollutants were reviewed and evaluated for possible inclusion in the NPS Model.

SWMM is an event-oriented model while STORM and HSP QUALITY are continuous simulation models. The accumulation functions for SWMM and STORM are essentially identical and can be stated as follows:

$$TOTDD = \begin{cases} DD * DRDRY, \text{ for } DRDAY \leq CLFREQ \\ DD * CLFREQ * \{1 + (1-REFF) + \ldots + (1-REFF)^{NCLEAN}\} \\ \qquad \text{for } DRDAY > CLFREQ \end{cases} \quad (1)$$

where TOTDD = total dust and dirt (D&D) on the land surface at the beginning of a storm
DD = daily accumulation of D&D
DRDAY = number of days since the previous storm event
CLFREQ = number of days between street sweepings
NCLEAN = DRDAY/CLFREQ
REFF = efficiency of street cleaning

This formulation calculates the total dust and dirt (D&D) accumulation between storm events. Both SWMM and STORM allow for the addition of the D&D remaining from the previous event. The total pollutant load is calculated as a function of the D&D accumulation, i.e., the D&D values are multiplied by pollutant factors (lb BOD/lb D&D) to obtain the surface accumulation of each pollutant. These pollutant factors are generally a function of land use and season of the year. The SWMM employs information from an American Public Works Association study in Chicago (48) to arrive at these factors, while the STORM bases its value on a study in Tulsa, Oklahoma (49).

The pollutant accumulation function in HSP QUALITY is not based solely on the D&D fraction of street litter; accumulation and removal rates must be specified for each pollutant to be simulated. The formulation is as follows:

$$L(T) = L(T-1) * (1-R) + Y \qquad (2)$$

where $L(T)$ = pollutant accumulation at time, T
$L(T-1)$ = pollutant accumulation at time, T-1
R = general removal rate
Y = pollutant accumulation

The general removal rate, R, is a function of street cleaning (efficiency and frequency), wind, and biochemical processes and can be evaluated as

$$R = P * E/D + W + K \qquad (3)$$

where P = fraction impervious area
E = efficiency of street cleaning on the impervious area
D = frequency of street cleaning
W = pollutant removal by wind
K = pollutant decay by biochemical processes

The above equation yields an approximate value of R that can be modified in the calibration process. R is considered a calibration parameter because of inaccuracies in attempting to quantify all removal processes. A study by Sartor and Boyd (50) indicates that stated efficiencies of street cleaning practices are inaccurate with respect to the small particle size fractions which are highly polluting. Also, the frequency of street cleaning is often inconsistent and other removal processes are ignored in the SWMM and STORM formulations. Thus, an accurate deterministic evaluation of the effects of removal processes is highly questionable. Calibration is a logical alternative in such situations.

Nonpoint pollutant transport is calculated separately for both impervious and pervious areas in all three models. In addition, SWMM and STORM simulate sediment transport, or erosion, from pervious lands by an entirely separate methodology. The method of calculating pollutant washoff from impervious areas is basically identical in SWMM, STORM, and HSP QUALITY. The premise is that the amount of pollutant washed off is proportional to the amount remaining

$$\frac{dP}{dt} = -KP \qquad (4)$$

where P = amount of pollutant on the land surface
K = proportionality constant

Rearranging and integrating leads to the basic form of the washoff function

$$\Delta P = P_0 - P = P_0(1 - e^{-Kt}) \quad (5)$$

where P_0 = pollutant initially on the land surface
P = pollutant on the land surface after time interval t
ΔP = Pollutant washed off during time interval t

With the assumptions that K is directly proportional to overland flow and 90 percent of P_0 is washed off during one hour at a runoff rate, r, of 0.5 inches per hour, K is evaluated as 4.6r and the equation becomes

$$\Delta P = P_0(1 - e^{-4.6rt}) \quad (6)$$

This is the basic form of the washoff equation used in all three models although there are other differences in the overall formulations. The SWMM and STORM functions adjust P_0 by an availability factor, A, which is also a function of runoff, r. Separate relationships were developed for suspended and settleable solids (STORM only) due to lack of agreement with observed values. The relationship for suspended solids is

$$A = .057 + 1.4\ r^{1.1} \quad (7)$$

As runoff increases larger particles become more "available" for transport. Without additional verification, the availability factors appear to be specific to the watershed and the observed data from which they were developed, thereby reducing the general applicability of the models.

HSP QUALITY does not include availability factors. However, accumulation and washoff are calculated separately for each pollutant; hence, the P_0 values are not tied directly to D&D accumulation. Calibration is used to modify pollutant accumulation and removal rates to best match the observed data.

The above discussions have been concerned only with impervious areas. Except for the process of soil erosion, pollutant washoff from pervious areas is handled in the same fashion. SWMM and STORM use the same value of K (4.6r) for both impervious and pervious areas. However, STORM and HSP QUALITY allow the user to specify the K value as an input parameter. The default value in HSP QUALITY for pervious areas assumes 50 percent pollutant washoff at a runoff rate of 0.5 inches per hour, resulting in K = 1.4r.

For pervious areas, sediment is a major pollutant for which simulation is a complex problem. At the present time, HSP QUALITY does not simulate the soil erosion process; the washoff function described previously is used for all nonpoint pollutants on both impervious and pervious areas. SWMM (University of Florida version) and STORM employ the Universal Soil Loss Equation (USLE) to simulate soil erosion from pervious areas (51). The USLE is

$$A = R*K*L*S*C*P \tag{8}$$

where
- A = annual soil loss per unit area
- R = rainfall factor
- K = soil-erodibility factor
- L = slope-length factor
- S = slope-gradient factor
- C = cropping management factor
- P = erosion control practice factor

The USLE was developed from statistical analyses of historical soil loss and associated data on numerous erosion plots at research stations across the country operated by the Agricultural Research Service. Guidelines for evaluating the various factors for specific geographic areas, soil conditions, and agricultural management practices are provided in the original publication (51). The rainfall factor, R, is the number of erosion index units in a normal year's rainfall, evaluated as the sum of the product of storm kinetic energy, E, and maximum 30-minute rainfall intensity (EI). The erodibility factor, K, is the erosion rate (soil loss per unit area) per erosion index unit, evaluated by R, for a specific soil under base conditions. The base conditions were defined as a cultivated continuous fallow plot with a 9 percent slope 72.6 feet long. The combined term RK corresponds to the potential erosion rate from the watershed under base conditions. The remaining factors (L, S, C, P) in the equation are evaluated as the rates of soil loss on the watershed to soil loss under the base conditions stated above; thus, L, S, C, and P adjust the potential rate for effects of slope length, land slope, cropping and management characteristics, and erosion control practices, respectively.

In the absence of greater understanding of the soil erosion process, the USLE is a tool for estimating average annual soil erosion and the impact of land management practices. During the past ten years, a vast amount of experience with the USLE and with evaluation of its factors has evolved. This experience has provided a valuable basis for more accurate quantification of the individual processes controlling soil erosion. However, the USLE has been modified numerous times to overcome inherent weaknesses in its formulation and to adapt the equation to localized conditions. Although each of the USLE factors can be evaluated on a storm event basis, the entire equation was "particularly designed to predict average annual soil loss for any specific field over an extended period" (51, p. 39). When used for this purpose, the USLE can provide estimates of average annual soil loss when more accurate methods are unavailable.

SWMM and STORM use the USLE methodology for simulation of soil erosion from pervious areas during storm events. This use of the USLE was rejected in the evaluation of algorithms for the NPS Model for the following reasons:

(1) The USLE methodology does not account for the effects of antecedent soil moisture or availability of detached soil particles. These conditions are critical to the accurate representation of runoff and sediment loss.

(2) The USLE contains no term to specifically account for the effects of overland flow, the major transport mechanism by which soil erosion occurs. Research has shown that runoff is the best single indicator of sediment yield from small watersheds (52, 53). This is reflected in recent modifications of the USLE to specifically include the effects of runoff (54, 55).

(3) Although the factors in the USLE are directly relevant to the soil erosion process (especially K, C, P), the formulation of the USLE does not specifically evaluate the mechanisms of soil detachment and transport; these are the major determinants of erosion during storm events.

(4) The USLE was originally developed for estimates of average annual soil loss from croplands east of the Rocky Mountains. It has had limited success in other areas and has been modified numerous times to adapt to local conditions.

In summary, SWMM, STORM, and HSP QUALITY were reviewed to investigate methods of representing the pollutant accumulation and transport functions important to nonpoint pollution. The pollutant accumulation functions of these models are based on daily accumulation as a function of land use, street cleaning practices, and season of the year. SWMM and STORM simulate pollutant accumulation solely as a function of D&D accumulation, while HSP QUALITY provides for independent accumulation of each water quality constituent. None of the models consistently represent the physical processes involved in both soil erosion and pollutant transport from impervious and pervious areas. The USLE as used in SWMM and STORM is not considered applicable to short-time interval simulation of the soil erosion process for the reasons stated above. In fact, a basic contradiction exists in the use of both the USLE and the pollutant washoff functions in SWMM and STORM. The effects of overland flow are specifically included in the "availability factors" and the pollutant washoff equation in both models. On the other hand, no factor for overland flow is in the USLE although pollutant transport is being simulated in both instances. The physical processes governing pollutant transport from the land surface are the same whether the phenomenon occurs on pervious areas, impervious areas, cropland, or forests. The magnitude of the relevant factors may vary, but the controlling processes are identical. Thus, a consistent approach is needed to represent the universal mechanisms involved in the transport and movement of all land surface nonpoint source pollutants.

NONPOINT POLLUTION SIMULATION BY THE QUAL SUBROUTINE

In light of the goals and scope of this project, and within the setting of existing simulation methods, the development of the QUAL subroutine was guided by the following criteria:

(1) Individual processes controlling nonpoint source pollution from the land surface should be represented as accurately as possible within the current state of technology.

(2) Nonpoint pollution from both pervious and impervious areas should be simulated in a consistent manner to emphasize the universal nature of the controlling transport processes.

(3) The methodology should be sufficiently flexible to accommodate all major land use categories and activities and should be applicable to the largest possible number of nonpoint pollutants.

(4) To the extent possible, the methodology should minimize the number of water quality parameters that must be evaluated through calibration with observed data in order to simplify application.

Obviously the criterion for simplification is somewhat contradictory to the development of a general model with technical algorithms based on the current state-of-the-art. The present understanding of pollutant accumulation, generation, and transport processes cannot provide an exact quantitative description; hence, the need for empirical parameters evaluated through calibration. In any case, the attempt to meet the above criteria in the development of the QUAL subroutine produced the following nonpoint pollutant simulation methodology:

(1) The transport, or washoff, process of pollutants from the land surface is simulated in the same manner on both pervious and impervious areas.

(2) Sediment is used as the indicator of nonpoint pollutants. Sediment accumulation and washoff is simulated for both pervious and impervious areas, and a user-input 'potency factor' specifies the pollutant content of the washed-off sediment. All water quality constituents except water temperature and dissolved oxygen content are simulated in this manner.

(3) Sediment from impervious areas will include both suspended and settleable solids measured in the surface runoff. In urban areas, sediment is often referred to as 'Total Solids'; sediment and total solids (suspended and settleable) are assumed to be identical in the NPS Model.

(4) Pollutant accumulation is simulated in terms of sediment accumulation on impervious areas and sediment accumulation and generation on pervious areas. Thus, impervious areas receive pollutants almost entirely from human activity, whereas pervious areas can generate sediment particles by the force of raindrop impact on the land surface.

Sediment and sedimentlike material was chosen as the indicator for nonpoint pollutants because it is the major constituent of nonpoint pollution from the land surface. This is the central theme throughout much of the present literature on nonpoint source pollution. From agriculture and construction areas, sediment loss is the primary concern as a pollutant itself and as a carrier for other pollutants (6, 56, 57). The same is true for silvicultural activities (6, 56, 58). In urban areas one would not expect sediment to be a major pollution problem. However, numerous studies have variously characterized the major pollutant in urban runoff as 'dust and dirt' (11), 'sediments' (50), 'suspended and settleable solids' (10), etc. In other words, sediment and sedimentlike material is the most common constituent in nonpoint pollution from urban, agriculture, silviculture, and construction areas. Thus, a method of representing soil erosion, sediment or pollutant accumulation, and sediment transport from both pervious and impervious land surfaces would be applicable to all the above land uses.

Application of the QUAL subroutine and the NPS Model is greatly simplified by using sediment as a pollutant indicator. Accumulation, detachment, and washoff parameters need to be evaluated only for sediment on pervious areas and impervious areas. On the other hand, if each pollutant was simulated separately, all parameters (accumulation, detachment, washoff) would need to be evaluated separately. Although individual simulation of each pollutant would likely produce more accurate results, the number of parameters and the required effort for parameter evaluation would increase substantially. Moreover, the available data on nonpoint source pollution is insufficient to warrant such a detailed approach. Thus, the use of sediment as a pollutant indicator satisfies the need for a consistent, flexible method for representing nonpoint pollution from various land uses and provides a reasonable compromise between algorithm complexity and simplicity of application.

QUAL Subroutine Algorithms

As indicated above, simulation of nonpoint source pollution from pervious and impervious areas is performed separately in the QUAL subroutine; hence, the component processes on pervious and impervious areas are discussed separately below.

Pervious Areas-

The processes on pervious areas simulated in the QUAL subroutine include (1) net daily accumulation of sediment by dustfall and human activities, (2) detachment of particles by raindrop impact into fine sediment material, and (3) transport of sediment fines by overland flow. On pervious areas detachment heavily outweighs dustfall and accumulation from land surface activities; hence, the accumulation algorithm will be discussed in the section on impervious areas where it is the sole source of surface sediments. However, accumulation is also simulated on pervious areas.

Pervious area simulation is presented first because research on the mechanisms involved in soil erosion provided the basis for the detachment and transport algorithms in the QUAL subroutine. These algorithms were initially derived from work by Negev at Stanford University (59) and have been subsequently influenced by the work of Meyer and Wischmeier (60) and Onstad and Foster (61). Although Meyer and Wischmeier enumerated four mechanisms, detachment and transport by rainfall and detachment and transport by runoff, only the two major mechanisms of detachment by rainfall and transport by overland flow are included in the QUAL subroutine. The algorithms for these two processes are identical to those in the ARM Model (21) and are as follows:

soil fines detachment:

$$RER(t) = (1 - COVER(T))*KRER*PR(t)^{JRER} \qquad (9)$$

$$SRER(t) = SRER(t - 1) + RER(t) \quad (10)$$

soil fines transport:

$$SER(t) = KSER*OVQ(t)^{JSER} \quad \text{for } SER(t) < SRER(t) \quad (11)$$

$$SER(t) = SRER(t) \quad \text{for } SER(t) \geq SRER(t) \quad (12)$$

$$ERSN(t) = SER(t)*F \quad (13)$$

where RER(t) = soil fines detached during time interval t, tonnes/ha
COVER(T) = fraction of land cover as a function of time, T, during the year
KRER = detachment coefficient for soil properties
PR(t) = precipitation during the time interval, mm
JRER = exponent for soil detachment
SER(t) = transport of fines by overland flow, tonnes/ha
KSER = coefficient of transport
JSER = exponent for fines transport by overland flow
SRER(t) = reservoir of soil fines at the beginning of time interval, t, tonnes/ha
OVQ(t) = total overland flow occurring during the time interval, t, mm
F = fraction of overland flow reaching the stream during the time interval, t
ERSN(t) = sediment loss to the stream during the time interval, t, tonnes/ha

In the operation of the algorithms, the soil fines detachment (RER) during each 15-minute interval is calculated by Equation 9 and added to the total fines storage (SRER) in Equation 10. Next, the total transport capacity of the overland flow (SER) is determined by Equation 11. Sediment is assumed to be transported at capacity if sufficient fines are available, otherwise the amount of fines in transport is limited by the fines storage, SRER (Equation 12). The sediment entering the waterway in the time interval is calculated in Equation 13 by the fraction of total overland flow that reaches the stream. A land surface flow-routing technique described in Appendix B determines the overland flow contribution to the stream in each time interval. After the fines storage (SRER) is reduced by the actual sediment entering the stream (ERSN), the algorithms are ready for simulation of the next time interval. Thus, the sediment that does not reach the stream is returned to the fines storage and is available for transport in the next interval.

The land cover variable in Equation 9, COVER(T), represents the fraction of the land surface effectively protected from the kinetic energy and detachment capability of rainfall. Mean monthly values are specified by the user. The NPS Model interpolates linearly between the monthly values to evaluate land cover on each day. Figure 7 demonstrates the land cover function in the NPS Model. In essence, the land cover function is the key to differentiating erosion rates on different land uses. Agricultural, silvicultural, and construction areas will have highly variable land cover with portions of the land surface completely exposed during certain seasons of the year. The land cover function in Figure 7 is typical for an agricultural watershed. Storm events occurring when the land is exposed can produce extreme sediment loss. On the other hand, the pervious portion of urban areas will include lawns, parks, golf courses, etc., that have a reasonably constant and complete vegetal cover. The kinetic energy of rainfall is effectively dissipated by the land cover with values of 90 to 95 percent of the area. Thus, judicious use of the land cover function in the NPS Model will allow simulation of various land surface conditions. Monthly cover factors can be estimated in terms of the 'C' factor in the USLE as COVER(month) = 1 - C(month) when the 'C' factor is evaluated on a monthly basis. Additional guidelines for evaluating the cover factors are provided in the User Manual, Appendix A.

Impervious Areas-

The processes of importance on impervious areas are the accumulation of pollutants on the land surface and transport of pollutants by overland flow. Accumulation of dust, dirt, debris, and other contaminants from streets, roads, and parking lots is the major source of nonpoint pollutants on impervious areas. As indicated previously, the composition of these pollutants is similar to sediment and is often measured as Total Solids (suspended and settleable). Thus, these pollutants are simulated as sediment on impervious areas.

Rates of sediment accumulation on impervious areas are a function of land use, street cleaning practices, and climatic factors such as wind and rainfall. Much of the research on accumulation rates has involved grab-sampling of runoff in urban areas; few data from continuous monitoring of storm runoff are available. Extrapolation of grab-sample data can be highly erroneous. Moreover, sampling of storm runoff may indicate actual pollutant loads but provides little information on accumulation rates which represent the potential pollutant load. The actual sediment washoff during a storm event depends on the amount of accumulated sediment prior to the event and the overland flow occurring during the event.

The most relevant studies on accumulation rates have been performed by the APWA (48) in Chicago and Sartor and Boyd (50) in 12 cities across

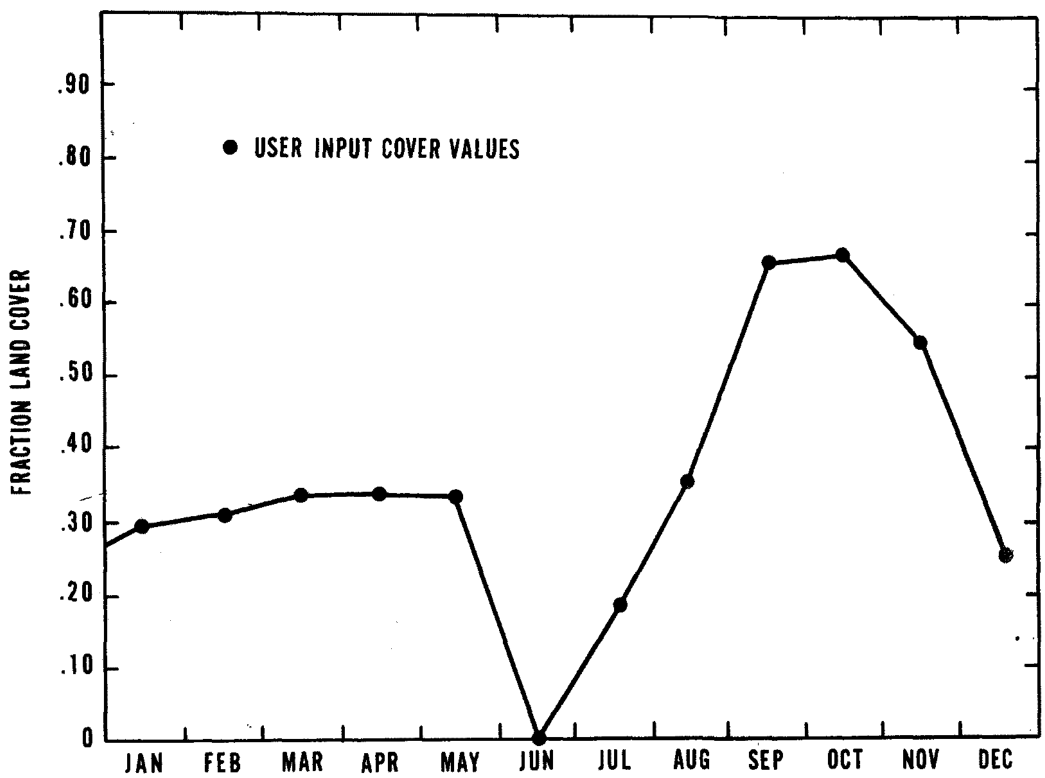

Figure 7. An example of the land cover function in the NPS model

the country. The APWA study of 1969 was one of the few attempts to directly measure the accumulation of urban nonpoint source pollutants. At various test sites throughout the city, the accumulation of the dust and dirt (D&D) fraction of street litter was determined. Then concentrations of various pollutants were related to the D&D fraction. In addition, the effects of street cleaning methods, catch basins, air pollution, and the chemicals from urban activities were investigated.

The study by Sartor and Boyd in 1972 included as one of its major goals the evaluation of the amounts and types of materials that accumulate on street surfaces and contribute to urban storm runoff pollution. Ten land use categories in twelve cities were included in the intensive sampling program. Numerous water quality indices were analyzed at each sampling point and accumulation rates between storms were evaluated as a function of total solids (TS) content. This study is the most complete survey of accumulation rates, urban pollutant composition, and street cleaning practices in urban areas.

These two studies provide the basis for evaluation of sediment accumulation rates in the NPS Model. Greater emphasis is placed on the study by Sartor and Boyd because of the comprehensive nature of the study and the emphasis on TS, or sediment, accumulation.

To evaluate the amount of sediment on the watershed prior to each event, the effects of non-runoff removal processes must be determined and incorporated into the accumulation function. The accumulation function simulates the net accumulation of sediment, i.e., the difference between accumulation and removal by mechanisms other than runoff. The major removal processes of concern are street cleaning and entrainment and transport by wind. The accumulation function in the QUAL subroutine is

$$TS(T) = TS(T-1)*(1-R) + ACCI \tag{14}$$

where TS(T) = sediment on the impervious land surface at time T
TS(T-1) = sediment on the impervious land surface at time T-1
R = fraction of sediment removed daily
ACCI = daily accumulation rate of sediment

R and ACCI are dependent on land use and season of the year. The formulation for pervious areas is identical to that above with separate accumulation and removal rates and separate sediment storage.

In the operation of the QUAL subroutine, the accumulation function is performed each day that a storm does not occur. Thus, as time between storm events increases, the accumulated sediment approaches a limiting value. From Equation 14

$$\Delta TS = - TS(T)*R + ACCI \qquad (15)$$

and at equlibrium $\Delta TS = 0$

$$TS(T) = ACCI/R \qquad (16)$$

This shows that the limiting value of TS(T) is simply the daily accumulation rate divided by the daily removal rate. Also, the maximum accumulation would be 1/R in terms of days of accumulation. Limiting accumulation of 8 to 10 days were found for BOD in a study at Oxney, England (62) and Sartor and Boyd (50) reported values of 10 to 12 days for accumulated total solids for all land uses combined.

Sediment transport from impervious areas is analogous to the same process on pervious areas. It is represented as follows:

$$TSS(t) = KEIM*OVQI(t)^{JEIM} \quad \text{for } TSS(t) < TS(t) \qquad (17)$$

$$TSS(t) = TS(t) \quad \text{for } TSS(t) \geq TS(t) \qquad (18)$$

$$EIM(t) = TSS(t)*F \qquad (19)$$

where
- TSS(t) = sediment transport during time interval t
- OVQI(t) = impervious area overland flow occurring in time interval t
- KEIM = impervious area coefficient of transport
- JEIM = impervious area exponent of transport
- TS(t) = reservoir of deposited sediment on impervious areas
- F = fraction of impervious overland flow reaching the stream in time interval t
- EIM(t) = sediment loss to the stream from impervious area in time interval t

As with pervious areas, sediment transport is limited in each time interval by the availability of deposited sediment. Thus, Equation 17 prevails if the movement of sediment is limited by the transport capacity of overland flow, and Equation 18 is applied if deposited sediment limits sediment washoff. Total sediment input to the stream (per unit impervious area) is proportional to the fraction of total overland flow entering the stream during the time interval, as indicated in Equation 19.

Quality of Overland Flow-

The pollutant content of overland flow is specified by user-input 'potency factors' that indicate the pollutant strength of the sediment for each pollutant being simulated, i.e., potency factor = (pollutant mass/sediment mass) x 100 %. In each time interval, the mass of sediment washed off the land surface is multiplied by the appropriate potency factor to obtain the mass of pollutant transported to the stream. As indicated earlier, this methodology was chosen because of the prevalence of sediment as a pollutant and as a carrier for other pollutants, and because of the simplicity of the approach. It is recognized that a simple linear relationship between pollutants and sediment is not applicable to all pollutants. Indeed, highly soluble pollutants may demonstrate little or no relationship to sediment loss. However, various water quality studies have shown a striking similarity in the behavior of sediment and pollutant washoff during storm events (8, 15, 24). This is especially true on relatively small watersheds (less than 200 hectares), where channel processes are less important, and when the data is plotted in terms of mass removal instead of concentration. The majority of non-soluble pollutants will demonstrate washoff and transport behavior similar to sediment. Many soluble pollutants will be transported like particulate matter during the short residence time on the land surface. Thus, the use of potency factors is applicable to a large number of pollutants. The results of this study (Section VIII) indicate that a reasonable simulation can be obtained with the use of potency factors varying with land use and season of the year. Obviously, the availability and strength of pollutants on the land surface is a function of a large number of variables; quantitative descriptions of these functional relationships are not available at the present time. Further, research is needed to define and describe these relationships that the potency factors attempt to represent.

The use of potency factors to indicate the pollutant content of overland flow can be represented as follows:

pervious areas:

$$POLP(t)_{p,l} = ERSN(t) * PMP_{p,l,m} \tag{20}$$

impervious areas:

$$POLI(t)_{p,l} = EIM(t) * PMI_{p,l,m} \tag{21}$$

where

$POLP(t)_{p,l}$ = mass of pollutant p transported from pervious areas in land use l during time interval t

$POLI(t)_{p,l}$ = mass of pollutant p transported from impervious areas in land use l during time interval t

$ERSN(t)_l$ = sediment loss from pervious areas in land use l during time interval t

$EIM(t)_l$ = sediment loss from impervious areas in land use l during time interval t

$PMP_{p,l,m}$ = potency factor for pollutant p on pervious areas in land use l for month m

$PMI_{p,l,m}$ = potency factor for pollutant p on impervious areas in land use l for month m

The subscripts in Equations 20 and 21 indicate the variations allowed in the QUAL subroutine; thus, the potency factors (PMP, PMI) for each pollutant (p) can vary according to land use (l) and month of the year (m). In each time interval the sediment loss from pervious (ERSN) and impervious (EIM) areas is calculated by Equations 13 and 19, respectively. Then Equations 20 and 21, using the appropriate potency factor, calculate the mass of pollutant transported to the stream. Pollutant concentrations can then be specified from the pollutant mass and the volume of flow during the time interval.

Overland Flow Temperature and Dissolved Oxygen-
The temperature and dissolved oxygen content of overland flow are generated by the QUAL subroutine for each simulation time interval. Each of these variables represent an important water quality constituent, almost always used to characterize the quality of receiving waters. Their inclusion in the NPS Model provides greater flexibility to interface with existing stream quality models.

The information available on water temperature and its driving forces is voluminous. It represents the importance associated with temperature as one of the major factors affecting aquatic and biochemical activities in water. Several attempts have been reported in the literature (63, 64, 65) to estimate in-stream water temperature from empirical relationships with various climatological factors such as radiation, wind velocity, cloudiness, and air temperature. Modeling in-stream water temperatures with an energy-balance approach involving these climatologic factors is a well established procedure (47, 66). However, simulation of overland flow temperature is a substantially different problem and has received little attention in the past. The temperature of overland flow depends on land surface characteristics, such as vegetation, impervious area, soil characteristics, etc., in addition to climatic conditions. Direct measurement of overland flow temperature is difficult, and research on the subject is scarce. Consequently, quantitative relationships for predicting overland flow temperature are not available.

Because of the short residence time on the land surface, a common assumption is that overland flow temperature equals the air temperature at the time of precipitation. The QUAL subprogram assumes a direct relationship between air temperature and overland flow temperature represented by a seasonal temperature correction factor as follows:

$$T_w = T_a * TCF \qquad (22)$$

where T_w = overland flow temperature for time interval t
T_a = air temperature for time interval t
TCF = temperature correction factor

As discussed in Section VI, T_a is calculated each hour from input max-min air temperature, and an assumed 24-hour distribution internal to the NPS Model. It is assumed that the value of the TCF will vary with factors such as watershed characteristics, time of the year, etc. and can be estimated by calibration. Results of testing have shown that a reasonable representation of overland flow temperature is produced with this methodology in many situations. As more information and experience with application of the NPS Model becomes available, this simplistic approach can be easily replaced by a more reliable scheme of modeling overland flow temperature.

The dissolved oxygen concentration of the overland flow is a direct function of its temperature. Since the NPS Model was developed for small watersheds where flow times are insufficient for any degrading processes to become significant, it is possible to assume that the concentration of DO in the overland flow is close to the saturation level. Therefore, the QUAL subroutine uses the following empirical non-linear equation relating DO at saturation to water temperature (67):

$$DO = 14.652 - 0.41022T_W + 0.00791T_W^2 - 0.0000777774T_W^3 \qquad (23)$$

where DO = dissolved oxygen in ppm
T_W = overland flow temperature in degrees C

QUAL Subroutine Operation-

The operation of the QUAL subroutine for simulating nonpoint pollutant accumulation and transport is illustrated in Figure 8. Operation is controlled directly by the MAIN subprogram. The algorithm consists of two alternate loops, each one iterated with different frequency, depending on the rainfall and runoff conditions as they are transferred from the LANDS subprogram. At the beginning of each simulation day, the MAIN subprogram determines whether or not a storm has occurred on that day; daily rainfall and/or the occurrence of overland flow indicate a 'storm' day. Whenever a 'storm' day occurs both the LANDS and QUAL subprograms are sequentially iterated throughout the whole day at 15-minute intervals (96 times). Otherwise the non-storm path is activated resulting in only one call to the LANDS and QUAL subprograms. In this case the role of the QUAL algorithm is limited to the evaluation of the daily increment of the sediment available for transport from the pervious (SRER) and impervious (TS) lands. The calculations are carried out iteratively for each of the land uses defined by the input data.

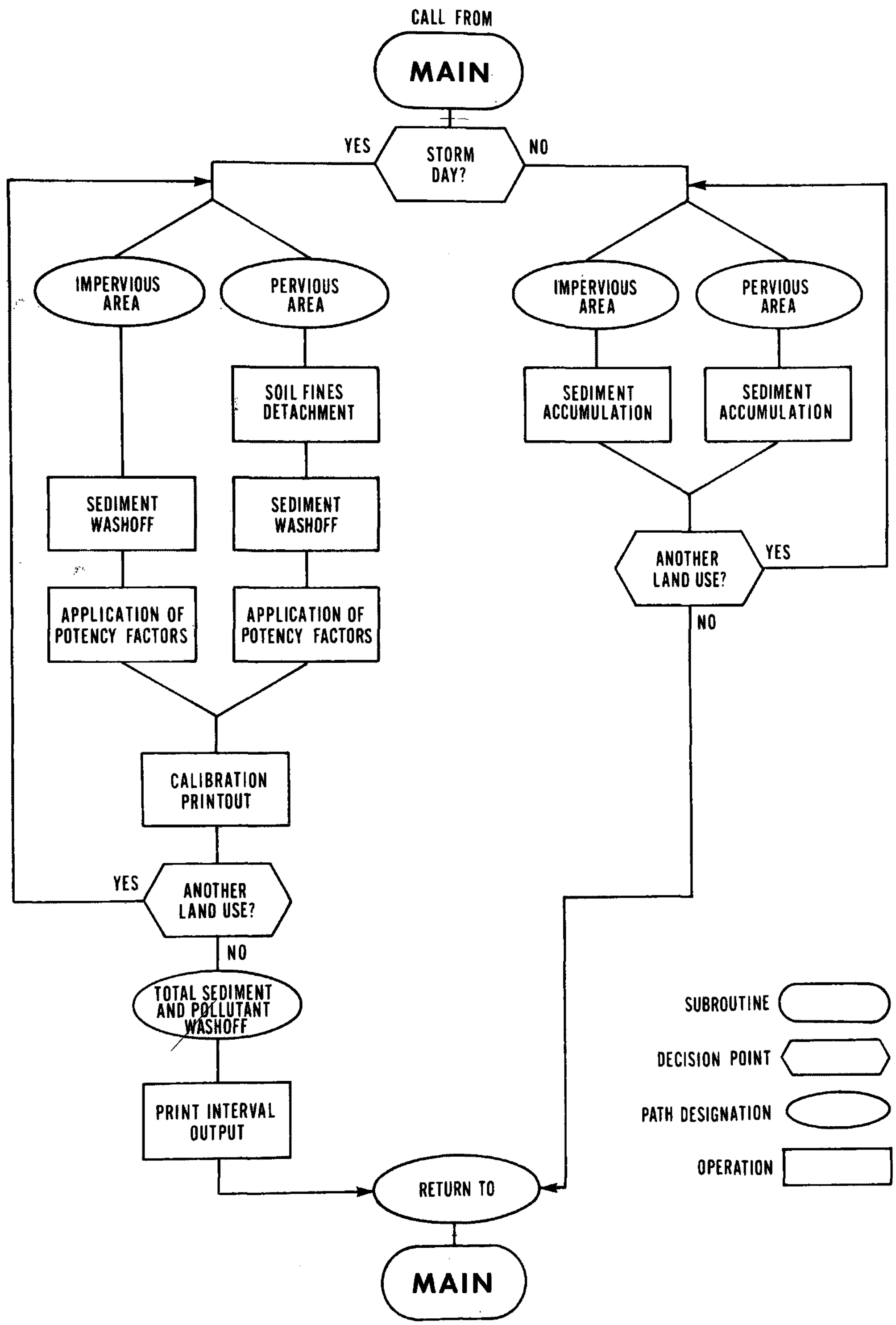

Figure 8. Functional flowchart of the QUAL subroutine

The factors considered are the daily accumulation rate in mass per unit area (lb/acre, kg/ha), and the removal effect R representing the percent of sediment loss due to wind and other factors not related to storm runoff. Both accumulation and removal rates must be specified separately for the pervious and impervious areas. An option to allow monthly variations in the accumulation and removal rates is included in the NPS Model.

The major portion of the QUAL algorithm pertains to the 'storm day' path. The key portions of this loop are the analytical representations of sediment fines generation, sediment washoff, and pollutant washoff from pervious and impervious areas. Simulation of these processes is carried out for each land use within the watershed. The aggregate quantities of the washed-off sediments and pollutants are summed to yield the total mass and the equivalent concentration of pollutants in the overland flow. The values of the water quality constituents selected for analysis are accompanied by the simulated values of runoff, water temperature, and dissolved oxygen. The results are printed each time interval and in monthly and yearly summaries. The User Manual describes the output options available in the NPS Model. Table 4 defines the input parameters of the QUAL subroutine, many of which have been discussed above. Section VIII demonstrates the application of the NPS Model to three urban watersheds and presents simulation results.

Table 4. QUAL SUBPROGRAM PARAMETERS

Sediment Generation and Washoff

COVVEC	fraction land cover of pervious surfaces within a given land use (monthly basis - 12 values)
JRER	exponent of rainfall intensity in soil splash equation
KRER	coefficient in soil splash equation
JSER	exponent of overland flow in sediment washoff equation from pervious areas
KSER	coefficient in sediment washoff equation from pervious areas
JEIM	exponent of overland flow in sediment washoff equation for impervious areas
KEIM	coefficient in sediment washoff equation for impervious areas

Sediment Accumulation and Removal

ACUP	daily accumulation rates on pervious surfaces
ACUPV	daily accumulation rates on pervious surface (monthly basis, 12 values), optional
ACUI	daily accumulation rates on impervious surfaces
ACUIV	daily accumulation rates on impervious surface (monthly basis, 12 values), optional
REPER	daily, non-runoff sediment removal rate from pervious surfaces
REPERV	daily non-runoff sediment removal from pervious surfaces (monthly basis, 12 values), optional
REIMP	daily non-runoff sediment removal from impervious surfaces
REIMPV	daily non-runoff sediment removal from impervious surfaces (monthly basis, 12 values), optional

Table 4 (continued). QUAL SUBPROGRAM PARAMETERS

Potency Factors

PMPVEC	potency factors for simulated water quality constituents washed off pervious surfaces
PMPMAT	potency factors for the simulated water quality constituents washed off pervious surfaces (monthly basis, 12 values for each constituent), optional
PMIVEC	potency factors for the simulated water quality constituents washed off impervious surfaces
PMIMAT	potency factors for the simulated water quality constituents washed off impervious surfaces (monthly basis, 12 values for each constituent), optional

Miscellaneous

TCF	temperature correction factor relating runoff and air temperatures (monthly basis, 12 values),
SRERI	initial deposit of sediment on pervious surfaces within a given land use
TSI	initial deposit of sediments on impervious surfaces within a given land use

SECTION VIII

MODEL TESTING AND SIMULATION RESULTS

The NPS Model was tested on three urban watersheds to evaluate the validity of the nonpoint pollution simulation methodology. The choice of watersheds was governed by the availability of meteorologic, hydrologic, and water quality data in a form that did not require extensive data reduction and analysis. Urban watersheds were chosen in response to the growing emphasis on the evaluation and control of nonpoint pollution in urban areas. Also, the size of the test watersheds was limited to a maximum of one to two square miles in order to minimize the influence of channel processes on the recorded data. In this way simulation results of the NPS Model, which does not simulate channel processes, could be realistically compared with the recorded observations.

The goals of the testing were to demonstrate the ability to (1) calibrate the NPS Model on representative watersheds, and (2) provide continuous information for the evaluation of nonpoint pollution problems. Since the hydrologic methodology has been extensively tested and verified in past work, the emphasis in this study was on the evaluation of the water quality simulation methodology. Because of time, financial constraints, and the scarcity of data, the degree of testing on each of the watersheds was not as extensive as would be recommended in an actual application of the Model. However, sufficient results were obtained to establish the capabilities and weaknesses of the NPS Model.

Although calibration is fully discussed in the User Manual, a brief explanation is necessary to evaluate the simulation results presented below. As mentioned previously, calibration is the adjustment of model parameters to improve agreement between simulated and recorded values. In the NPS Model, calibration is performed for hydrology, sediment, and water quality parameters in that order. Sediment calibration cannot be initiated until the hydrologic calibration is completed; likewise, water quality calibration follows sediment calibration. In each step, recorded and simulated values are compared for both monthly volumes (or mass) and individual storm events if the data is available. Lack of data for any particular comparison severely hampers the entire calibration.

The three test watersheds are: the Third Fork Creek, Durham, North Carolina; the Manitou Way Storm Drain, Madison, Wisconsin; and the South Seattle watershed, Seattle, Washington. Each of these watersheds and the available data is described. Simulation results are presented and discussed, followed by the general conclusions obtained from the NPS Model testing.

THIRD FORK CREEK: DURHAM, NORTH CAROLINA

Watershed and Data Description

The Third Fork Creek basin is located in the eastern section of the North Carolina Piedmont, a region of gently rolling hills. The stream flows in a southerly direction and is tributary to the New Hope, Haw, and Cape Fear River systems. Upper Third Fork Creek, simulated in this study, drains an area of 433 hectares (1,069 acres) located within the city limits of Durham, North Carolina. As shown in Figure 9, the drainage basin is primarily composed of two shallow valleys with relatively minor flood plains along the lower reaches of the streams. Surface runoff generally follows natural drainage paths with a few man-made channels. No storm sewer system exists; storm runoff occurs largely as surface runoff in street gutters, small pipes, and culverts under roads.

The region experiences a moderate climate without distinct wet and dry seasons. Summer storms tend to be brief, high intensity thunderstorms and convective showers. Winter and spring storms are of longer duration and lower intensity and are caused by migratory low pressure weather systems. Mean annual precipitation is approximately 1,200 millimeters (47 inches) of which less than 25 millimeters (1 inch water equivalent) occurs as snowfall with little significant accumulation.

The Third Fork Creek basin represents a typical urbanized area in the Piedmont region of the Southeastern United States. The basin encompasses a variety of land uses, including:

high and low density housing units of varying quality
undeveloped land

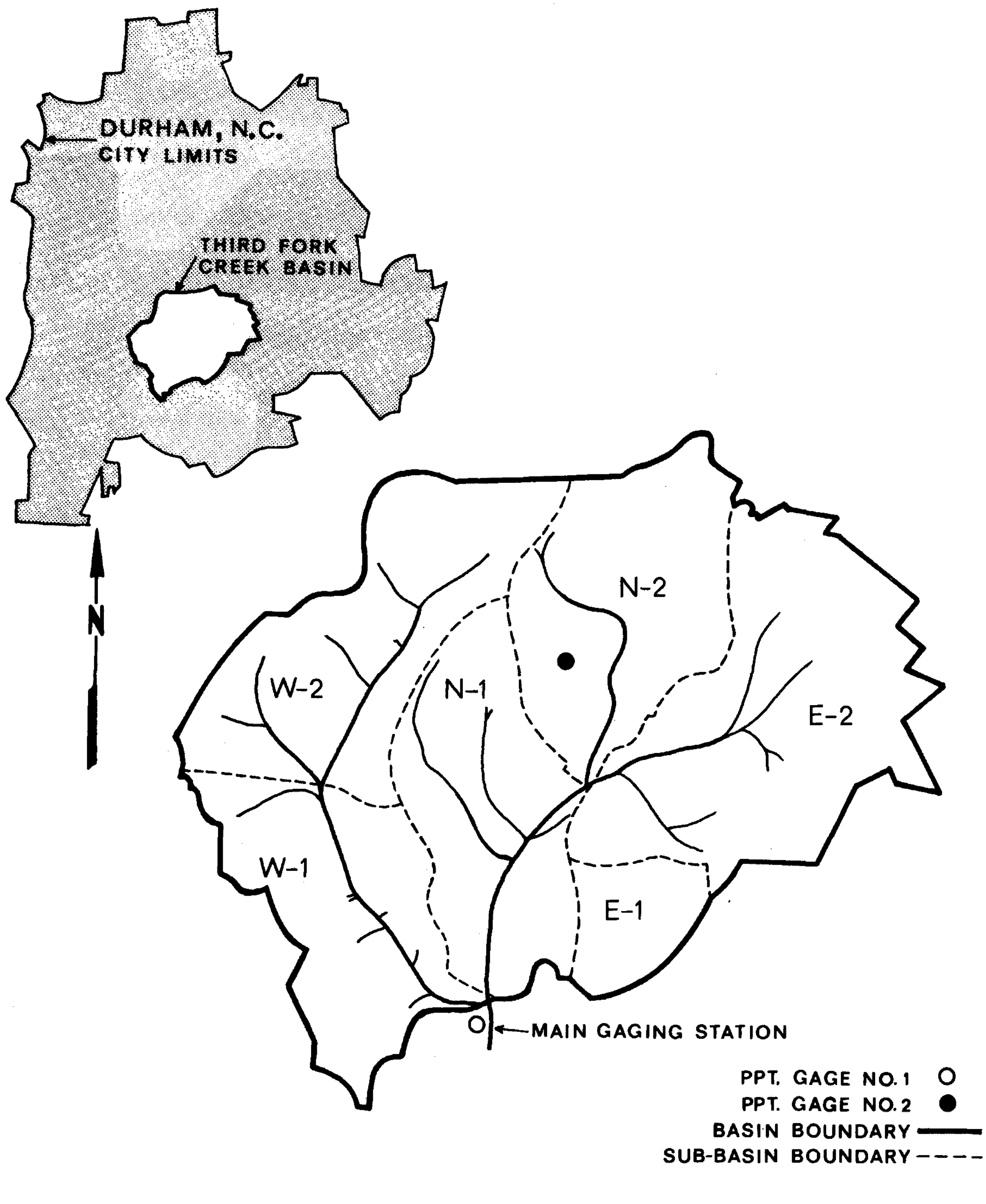

Figure 9. Third Fork Creek, Durham, North Carolina

shopping centers
portion of the central business district
institutional buildings (churches and schools) among scattered, small businesses
an urban redevelopment section
a tobacco processing plant
a completed section of expressway
a cemetery
slums
railroad yard
a flood plain utilized mainly as a city park

Table 5 summarizes the major land use characteristics for the subbasins shown in Figure 9.

The data available for applying the NPS Model to Third Fork Creek were the most extensive of any of the test watersheds. Previous water quality studies on the basin by Colston (8) and Bryan (68) provided land use and topographic information. The report by Colston (8) supplied necessary hydrology and water quality data for calibration of the NPS Model. Table 6 summarizes the data used in simulation of Third Fork Creek. Continuous meteorologic data series were developed to coincide with the period of record of available water quality data, i.e., October 1971 to March 1973. A continuous record of 15-minute precipitation was developed from the Blue Cross gage (ppt. no. 2 in Figure 9) and augmented for missing periods with recorded hourly data published for the Raleigh Airport gage. The resulting data series was checked for consistency with precipitation data at the basin outlet (ppt. no. 1 in Figure 9) and daily published values for Durham. Daily pan evaporation data was obtained from published data at Chapel Hill (16 kilometers southwest of Durham). Maximum and minimum air temperature data from Durham completed the meteorologic data requirements. Continuous daily streamflow and monthly runoff volumes were obtained from U.S. Geological Survey records for the upper Third Fork Creek basin. The Colston report (8) provided detailed storm hydrographs and water quality constituent concentrations for 36 storm events throughout the 18-month sampling period. Although the water quality measurements were not continuous (i.e., available for every storm event), they represent an extensive compilation of data on urban runoff quality. Tables 7 and 8 summarize a portion of the data contained in the Colston report.

Table 5. THIRD FORK CREEK LAND USE CHARACTERIZATION BY SUB-BASINS

Sub-basin	Area		Population Density Per Acre	Physical Features			% of Residential Dwellings of			Percent Land				Sub-basin Surface Characteristics % of Sub-basin			
	Acres	% of Total		Stream Length Feet	Stream Slope %	Mean Land Slope %	Low Quality	Med. Quality	High Quality	Resident.	Comm. & Indus.	Pub. & Inst.	Unused	Paved	Roof-tops	Unpaved Streets	Vegetation
E-1	56	5.2	13.5	1312	3	9.2	100	0	0	100	0	0	0	5	7	12	76
E-2	263	24.6	6.9	3221	1.4	5.2	100	0	0	50	36	9	5	27	13	3	57
N-1	183	17.1	3.8	3350	1.0	7.4	6	52	42	63	8	19	10	16	5	1	78
N-2	191	17.9	1.5	3484	2.1	8.1	62	31	7	18	44	13	25	33	12	1	54
W-1	169	15.8	3.5	3282	0.9	8.4	0	30	70	85	0	15	0	16	5	3	77
W-2	207	19.4	10.8	2610	1.8	9.1	62	38	0	73	4	9	14	11	9	6	74
Total Basin	1069	100%	6.0	-	-	-	24	27	49	59	19	12	10	20	9	3	68

Source: Colston (8), p. 13

Table 6. DATA SUMMARY FOR THIRD FORK CREEK

Type	Station Number	Location	Period of Record	Time Interval	Comments
Precipitation	-	Synthesis	10/71-3/73	15 min	See note a
	-	Blue Cross	10/71-3/73	5 min	Selected storms within basin
	-	Gaging Station	10/71-3/73	5 min	Selected storms within basin
	7069	Raleigh AP (20 SE)	10/71-3/73	hourly	
	251503	Durham	10/71-2/73	daily	
Evaporation	167703	Chapel Hill (12 SW)	10/71-2/73	daily	Adjusted with monthly pan coefficients
		Lumberton (95 S)	3/73	daily	Adjusted with monthly pan coefficients
Max-Min Air Temperature	251503	Durham	10/71-3/73	daily	
Streamflow	02097243	Third Fork Creek	10/71-3/73	daily	Units - cfs
	02097293	Third Fork Creek	10/71-3/73	irregular intervals less than 30 minute	36 selected storm events Colston report (8)
Water Quality	02097293	Third Fork Creek	1-/71-3/73	irregular intervals less than 30 minutes	36 selected storm events Colston report (8)

a Precipitation record used is a synthesis using the Blue Cross gage where available, and filled in by the Raleigh A.P. gage. The resulting 15-minute record was checked against the gage at the streamflow gaging station and the daily Durham gage.

Table 7. HYDROLOGIC DESCRIPTION OF SELECTED URBAN RUNOFF EVENTS ON THIRD FORK CREEK

Date	Storm No.	Rainfall Inches	Duration Hours	Intensity In/hr	Runoff Inches	Runoff Coefficient	Peak Discharge CFS	Days Since Last Storm	No. Samples Taken
10/23/71	1	1.55	32.5	0.047	0.88	0.54	33.2	3.25	15
11/24/71	2	← NO PRECIPITATION RECORDS AVAILABLE →						34.0	13
12/16/71	3	0.05	0.5	0.1	0.003	0.0061	2.5	4.0	10
12/20/71	4	0.43	19.5	0.022	0.15	0.34	31.3	0.5	16
1/4/72	5	0.2	2.5	0.08	0.04	0.19	22.6	4.75	9
1/10/72	6	0.55	12.0	0.046	0.19	0.34	63.0	1.0	19
2/1-2/72	7	1.19	10	0.119	0.84	0.7	138.4	11.5	27
2/12-13/72	8	0.96	10	0.096	0.54	0.56	126.6	9.0	20
2/18/72	9	0.44	8	0.049	0.2	0.45	32.0	5.5	27
2/23/72	10	0.13	0.5	0.26	0.04	0.29	22.0	5.5	8
2/26/72	11	0.19	0.5	0.38	0.03	0.18	19.0	2.83	23
3/8/72	12	0.04	0.083	0.48	0.01	0.25	4.3	4.88	15
3/16/72	13	0.6	10.33	0.058	0.36	0.59	51.8	7.25	23
3/31/72	14	0.46	11.33	0.04	0.15	0.33	40.6	9.5	23
4/12/72	15	0.33	2.17	0.15	0.12	0.35	73.0	4.25	17
5/3/72	16	1.14	7.25	0.15	0.47	0.41	135.7	21.0	21
5/14/72	17	0.71	8.0	0.089	0.29	0.41	109.0	5.5	24
5/22/72	18	0.92	15.5	0.059	0.513	0.56	349.0	5.0	9
5/30-31/72	19	0.25	10.0	0.025	0.03	0.12	29.9	5.62	8
6/20/72	20	0.24	6.5	0.037	0.07	0.29	75.4	20.5	16
6/28/72	21	1.78	2.13	0.83	1.55	0.87	1740	7.17	5
7/11/72	22	0.1	0.5	0.2	0.005	0.054	2.25	6.54	4
7/12/72	23	0.33	3.83	0.086	0.083	0.25	36.2	7.33	15
7/17/72	24	0.26	1.0	0.26	0.15	0.57	125.0	5.25	7
7/31/72	25	0.38	2.5	0.15	0.34	0.9	152.0	0.75	20
8/28/72	26	0.06	2.1	0.028	0.004	0.066	2.58	6.54	3
9/17/72	27	1.51	3.3	0.45	0.7	0.46	700.0	11.3	10
9/21/72	28	0.5	9.0	0.055	0.083	0.16	41.4	3.5	10
10/5/72	29	2.36	26.0	0.34	2.07	0.88	872.0	5.0	7
10/19/72	30			← RECORDERS INOPERABLE →					11
11/14/72	31	0.74	3.63	0.2	0.25	0.34	120.8	6.0	9
11/19/72	32	0.79	4.0	0.19	0.48	0.61	106.0	2.45	20
11/30/72	33	0.5	14	0.04	0.09	0.18	57	4.6	12
1/19/73	34	0.11	1.25	0.09	0.03	0.30	27.8	4.2	26
2/26/73	35	0.4	1.6	0.25	0.09	0.24	83	12.1	3
3/21/73	36	0.25	5.0	0.05	0.05	0.23	38	4.1	16

Source: Colston (8), p. 37

Table 8. AVERAGE AND STANDARD DEVIATION OF SOLIDS AND ORGANICS FROM THIRD FORK CREEK

Storm Number	Total Solids mg/l		Volatile Solids mg/l		Total Suspended mg/l		Volatile Suspended mg/l		COD mg/l		TOC mg/l		BOD mg/l	
	Avg	σ	Avg	σ	Avg	σ	Avg	σ	Avg	σ	Avg	σ	Avg	σ
1	226	27			89	38			25	14			18	14
2	538	143			274	164			259	62				
3	571	186			163	86			111	21	30	7		
4									171	45	36	7		
5	520	264			346	272			146	89	35	34	18	13
6	676	294			474	249			141	60	25	11	17	12
7	1675	492			1459	535			195	103	36	41	6	6
8	1423	874			1233	949			143	104	33	16		
9					1754	1194	75	91	149	116	24	17	2	.4
10	982	384			572	421			125	96	36	27		
11	1169	453			990	733			171	146	36	25		
12	391	63	78	18	146	58	15	8	82	39	36	10	15	11
13	913	574	215	84	687	472	119	68	176	144	44	30	20	12
14	1124	435	147	39	1087	492	92	36	123	73	46	20		
15	960	412	148	29	843	429	121	40	89	49	36	12	18	9
16	1932	1273	182	65	2596	2107	152	102	257	190	17	12		
17	1583	506	133	44	1525	655	132	208	150	175	15	8	42	11
18	1215	1197	107	17	849	1117	76	15	41	7	16	5		
19	991	426	110	51	899	576	82	74	144	106	41	25	5	3
20	871	324	145	40	895	789	129	101	220	135	39	18	55	14
21	2460	467	288	88	2732	725	240	67	271	130	73	30	105	23
22	3940	2820	500	452	2332	1090	380	395	402	430	165	148	73	10
23	682	319	168	29	554	290	40	27	96	52	26	9	100	5
24	3570	908	485	102	2889	1266	318	129	348	198	94	41	80	19
25	3080	1117	224	123			136	93	187	79	48	14	16	2
26	5423	2597	323	127	3913	2204	152	101	184	80	50	18	220	10
27	3300	3076	283	182	2522	2434	221	149	253	232	51	41	41	24
28	1147	343	147	38	1024	376	71	25	140	60	21	11		
29	1487	664	186	60	1326	624	105	49	142	59	38	16	138	15
30					1340	1100	147	24	157	69	44	13	182	60
31	1050	588	242	56	83	62	14	7	132	83	49	15	80	74
32	1144	913	138	43	777	788	120	53	110	77	34	10		
33	1497	542	260	41	1246	550	145	40	93	28	38	14	49	20
34	1822	941	285	135	1463	923	188	97	374	103	105	35	50	12
35	1234	258	284	45	1029	288	136	10	289	101	99	19	100	20
36	719	152	177	30	643	202	104	17	92	31	31	14		

Source: Colston (8), pp. 38 and 44

Calibration and Simulation Results

The calibration of the NPS Model on Third Fork Creek was performed on 18 months of data in order to coincide with the period of record of available water quality data. The monthly simulation results are presented in Figure 10 and Table 9, and the final Model parameter values are listed in Table 10. Comparison of monthly recorded and simulated values was possible only for runoff since continuous water quality observations were not available. Because of time and financial considerations, water quality calibration and simulation was limited to three constituents: sediment (reported as total solids by Colston), BOD, and SS.

As shown in Figure 10, simulated and recorded monthly runoff volumes agree quite well. In the initial trials, simulated monthly runoff and storm flows were consistently and uniformly low throughout the calibration period. Analysis of the annual water balance indicated a possible bias in the synthesized input rainfall derived from hourly rainfall at Raleigh Airport, 32 kilometers southeast of the watershed. Consequently, the precipitation adjustment factor, K1 (see User Manual, Appendix A), was set at 1.4 to increase the precipitation by 40 percent. This correction substantially improved the simulation of both monthly runoff volumes and storm flows. Ideally, hydrologic calibration should be performed for a minimum of two to three years to obtain parameters evaluated over a range of hydrologic conditions. Thus, the calibration of Third Creek was based on a shorter period than would be normally recommended. Since the emphasis of this study is on nonpoint pollution, the hydrologic calibration is sufficiently accurate to demonstrate the NPS Model capabilities. Further calibration efforts would be recommended if the NPS Model is used for evaluation of nonpoint pollution control plans in the Third Fork Creek Basin.

The lack of continuous water quality observations prevented comparison of simulated and recorded monthly pollutant loading. Consequently, water quality calibration was based on the simulation of individual storm events. The simulated monthly pollutant loading values shown in Figure 10 demonstrate the dependence of BOD and SS on sediment loading, as represented in the NPS Model. Observed monthly values would likely show a similar relationship especially for SS. Since BOD may include a soluble component, some deviation may be expected. However, overall BOD washoff from the land surface will be closely related to sediment washoff in most cases.

Although observed monthly pollutant loadings were not available, Colston did estimate the total 1972 loadings for various pollutants. The

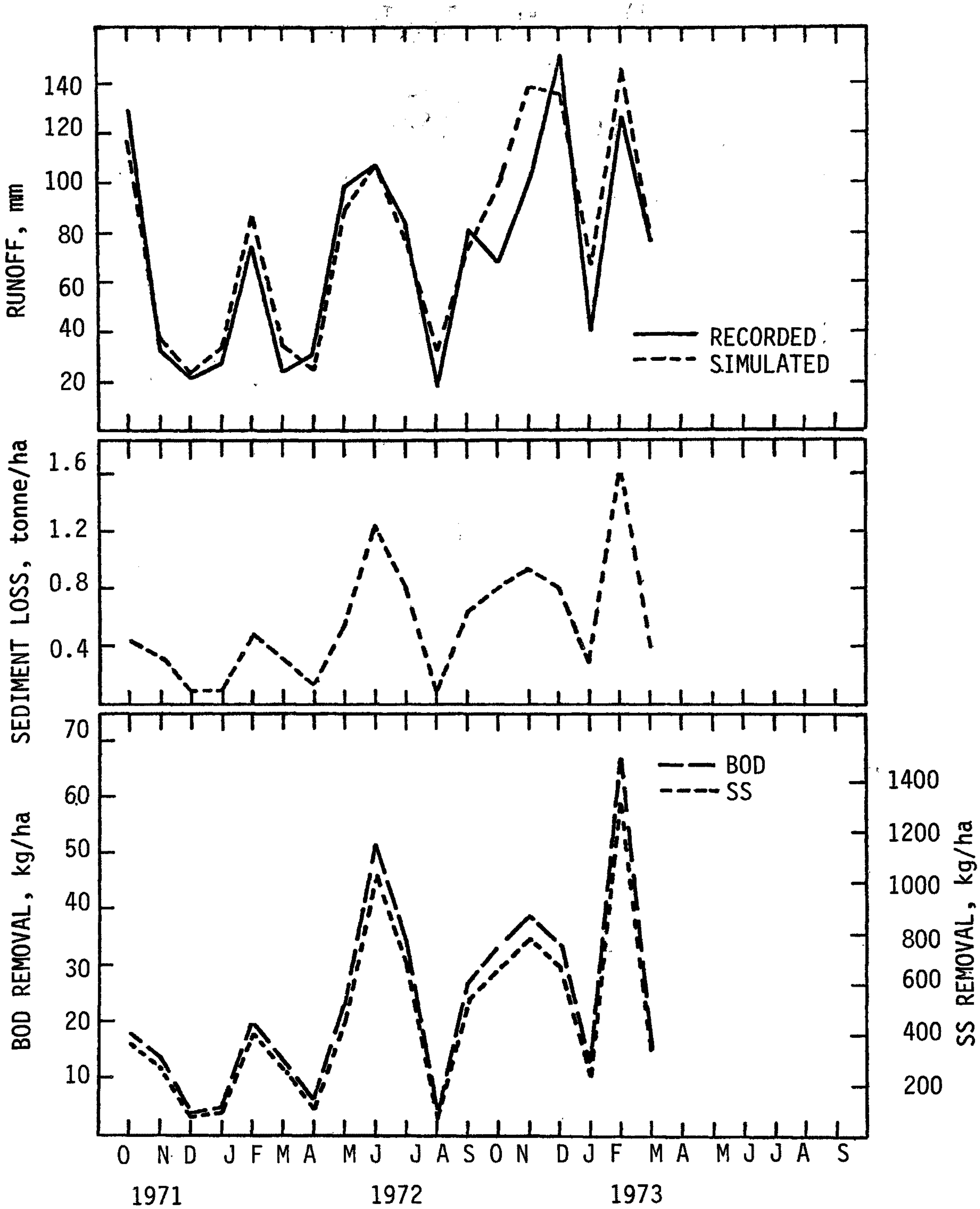

Figure 10. Monthly simulation results for Third Fork Creek (Oct. 1971-March 1973)

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Table 9. MONTHLY SIMULATION RESULTS FOR THIRD FORK CREEK (October 1971-March 1973)

Month	Runoff		Simulated Quality Constituents		
	Recorded (mm)	Simulated (mm)	Sediment (tonnes/ha)	BOD (kg/ha)	SS (kg/ha)
1971					
October	131	119	0.47	18.9	336
November	33	38	0.35	14.1	250
December	21	25	0.10	4.2	74
1972					
January	28	35	0.13	5.3	95
February	75	88	0.51	20.5	364
March	24	35	0.35	14.1	250
April	31	25	0.15	6.2	109
May	100	91	0.60	23.9	424
June	109	108	1.32	53.0	942
July	83	77	0.86	34.5	611
August	18	32	0.09	3.6	64
September	82	74	0.69	27.4	487
October	68	100	0.86	34.3	609
November	102	141	1.00	40.1	711
December	154	138	0.86	34.4	611
1973					
January	41	67	0.31	12.5	223
February	129	148	1.73	69.2	1229
March	77	78	0.44	17.6	311
Total	1306	1419	10.83	433.8	7700
Total for 1972	874	944	7.43	297.3	5277

Table 10. NPS MODEL PARAMETERS FOR THE THIRD FORK CREEK WATERSHED (English units)

HYDROLOGY

UZSN	0.4	NN	0.30	K1	1.4
LZSN	6.0	L	300	PETMUL	1.0
INFIL	0.04	SS	0.10	K3	0.25
INTER	2.0	NNI	0.15	EXPM	0.15
IRC	0.5	LI	600	K24L	0.0
AREA	1069	SSI	0.10	KK24	0.99

Initial Conditions: October 1, 1971

UZS	0.0	LZS	2.25

SEDIMENT AND WATER QUALITY

JRER	2.2	JEIM	1.8
KRER	1.5	KEIM	0.3
JSER	1.8	TCF	12*1.0
KSER	0.3		

		Open Land	Residential	Commercial	Industrial
ARFRAC		0.10	0.60	0.17	0.13
IMPKO		0.05	0.18	0.55	0.75
COVVEC		12*0.90	12*0.95	12*0.90	12*0.90
PMPVEC:	BOD	4	4	4	4
	SS	71	71	71	71
PMIVEC:	BOD	4	4	4	4
	SS	71	71	71	71
ACUP		30	70	75	80
ACUI		30	70	75	80
REPER		0.05	o.05	0.05	0.05
REIMP		0.08	0.08	0.08	0.08
Initial Conditions: October 1, 1971					
SRERI		1758	1880	2658	2758
TSI		106	246	266	284

estimates were based on regression equations developed from data on the 36 water quality events sampled and extended to all 66 events that occurred on the Third Fork Creek watershed in 1972. The predicted loadings were then adjusted to correct a bias in the automatic sampling technique and to subtract the estimated pollutant content of the base flow. The resulting estimates for sediment and SS are shown below with simulated loadings from the NPS Model. Colston did not estimate BOD loadings due to questions on the reliability of the measured BOD values.

1972 Annual Pollutant Loadings in Urban Runoff
from Third Fork Creek
(kg/ha)

	Estimated by Colston (8)	NPS Model Simulation
Sediment (or TS)	7952	7430
BOD	-	297
SS	7411	5277

The simulated values are reasonably close to Colston's estimates. Moreover, the effects of channel processes and the bias noted by Colston in his automatic sampling procedure would tend to produce measured pollutant loadings higher than the real nonpoint contributions.

Simulation of storm events indicated the importance of channel processes in the Third Fork Creek watershed. Recorded and simulated flow and sediment concentrations are presented in Figures 11, 13, 15, and 17 for selected storms, whereas recorded and simulated BOD and SS concentrations are provided in Figures 12, 14, 16, and 18. These results must be evaluated in light of the effects of channel processes on both flow and quality. With an area of 433 hectares, the Third Fork Creek basin approaches the upper limit of applicability for the NPS Model. A significant baseflow component and well-defined natural drainage channels indicate the occurrence of channel processes. Colston provides numerous photographs of the stream channel system; in many places it was clogged with trash, natural debris, and deposited sediment.

One of the hydrologic impacts of a defined channel system is to decrease the time variation of runoff as a result of channel storage. Thus, natural channel systems generally decrease peak flows from immediate

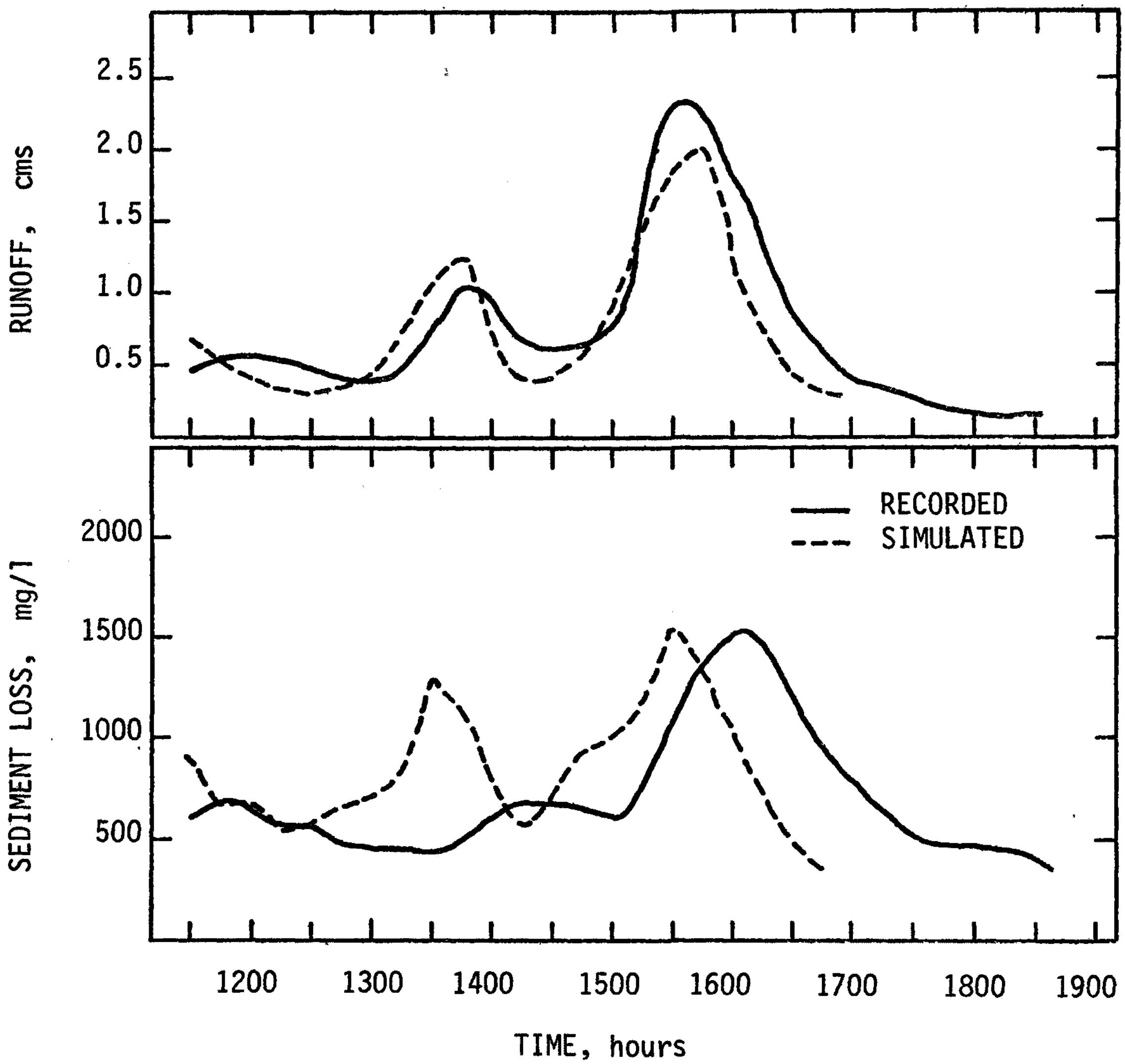

Figure 11. Runoff and sediment loss for Third Fork Creek for the storm of January 10, 1972.

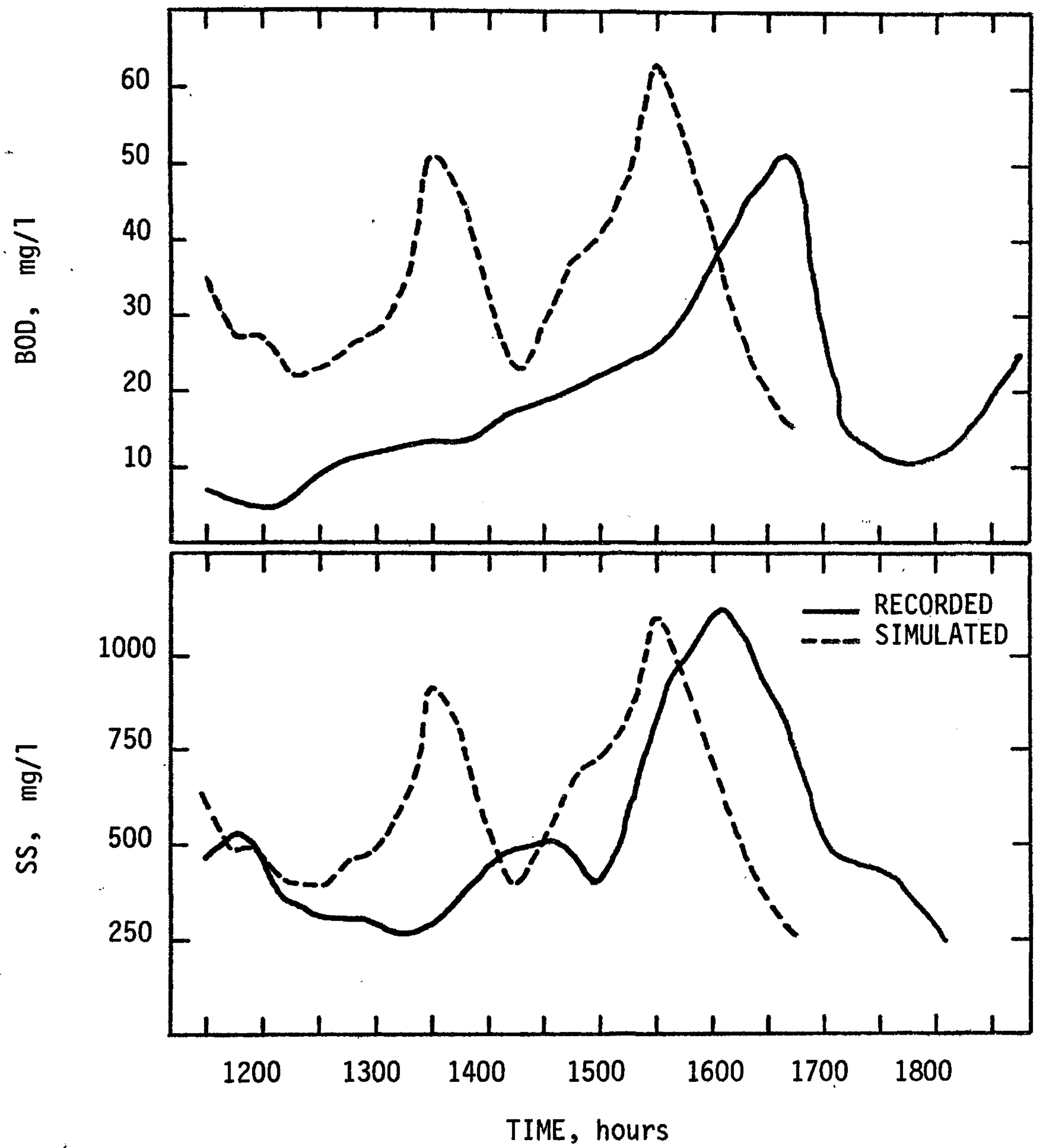

Figure 12. BOD and SS concentrations for Third Fork Creek for the storm of January 10, 1972.

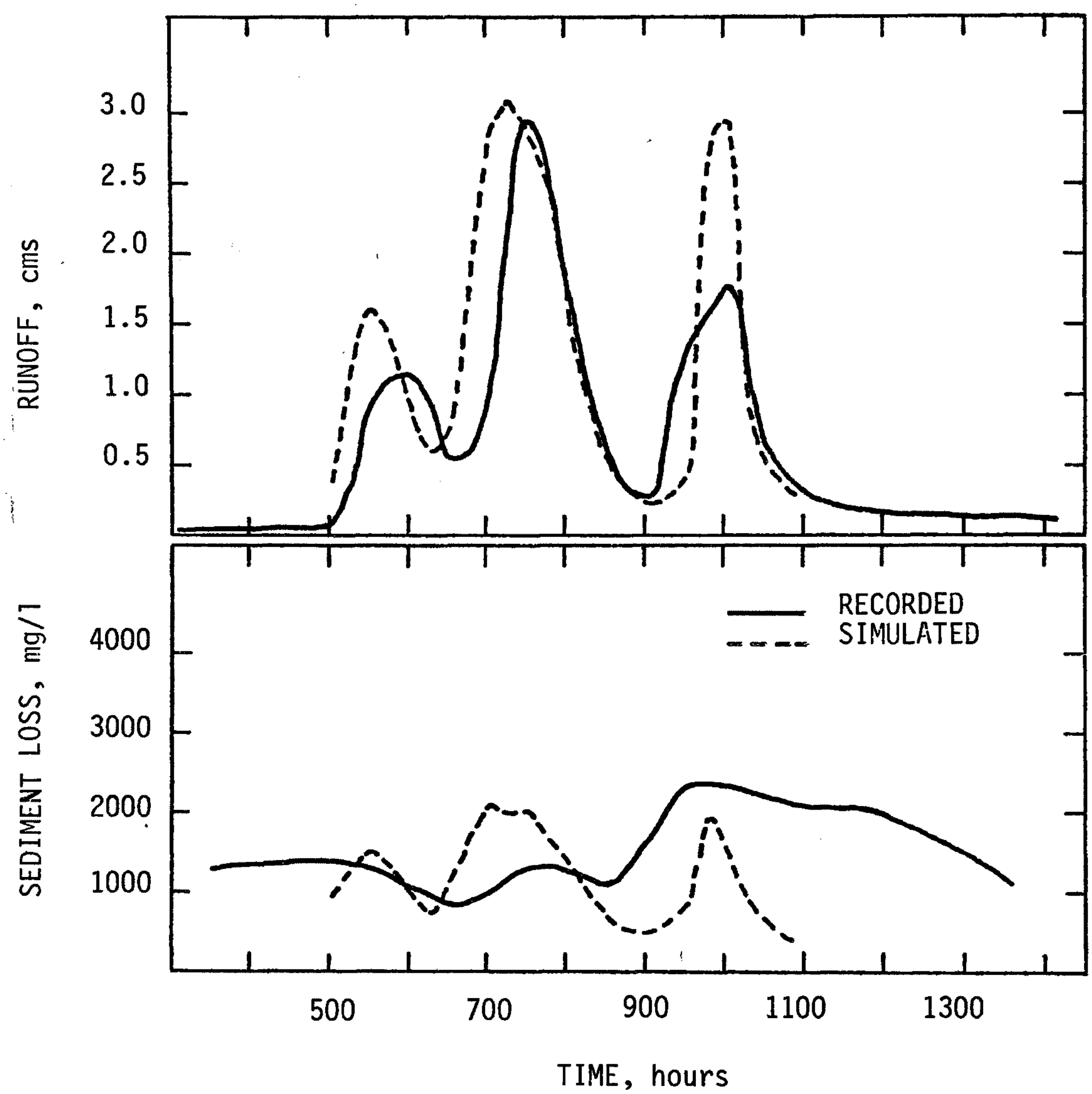

Figure 13. Runoff and sediment loss for Third Fork Creek for the storm of May 14, 1972.

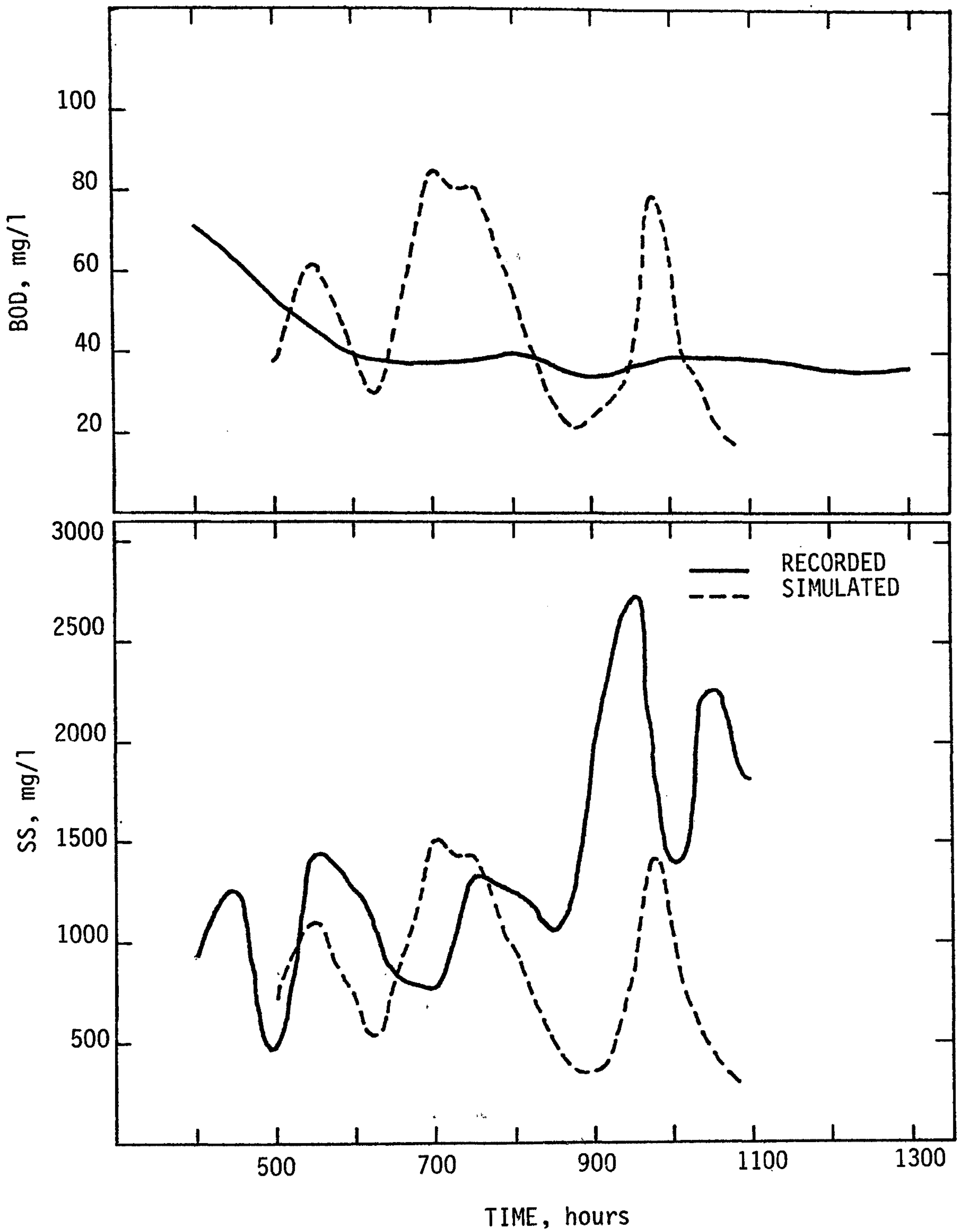

Figure 14. BOD and SS concentrations for Third Fork Creek for the storm of May 14, 1972.

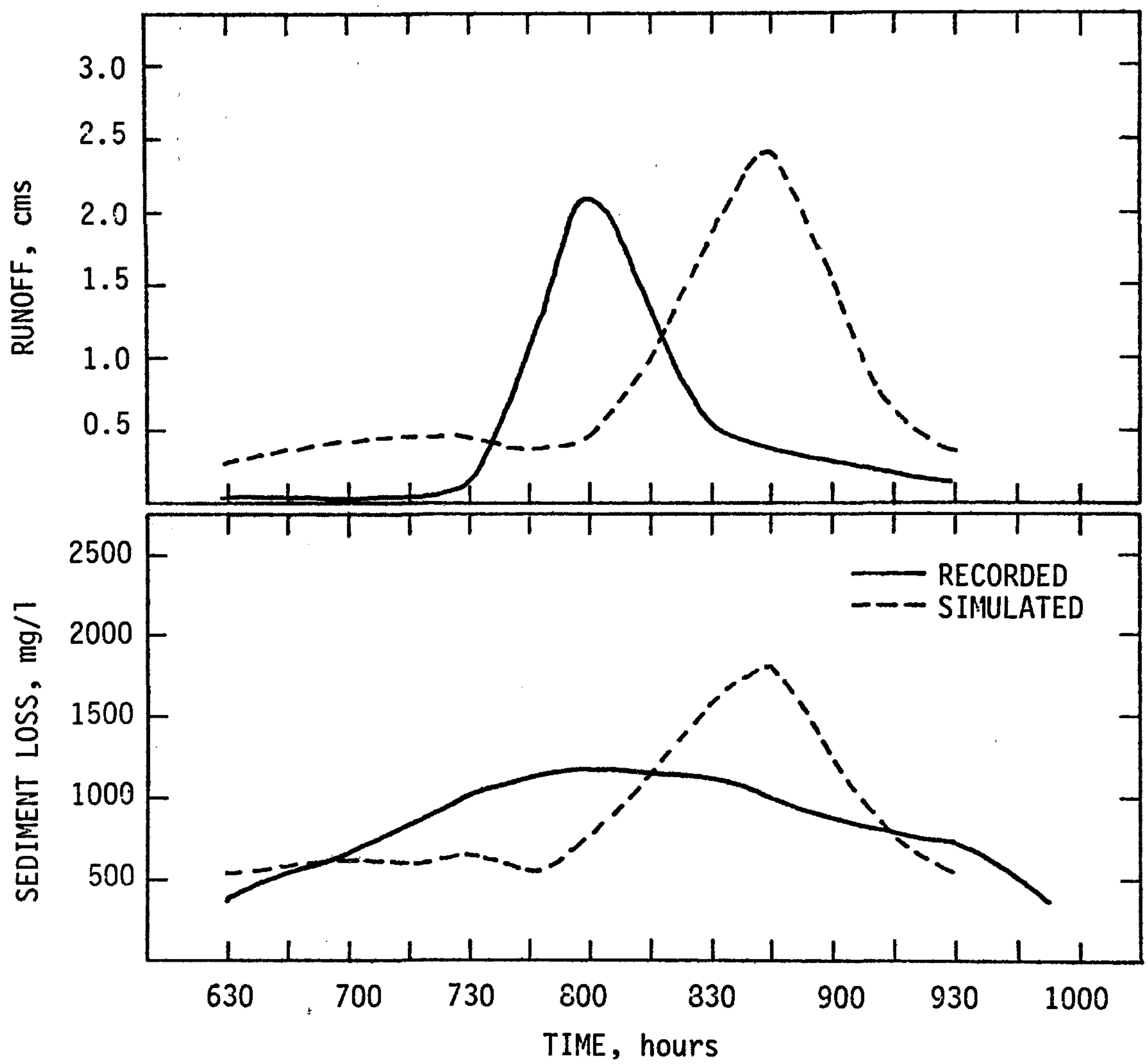

Figure 15. Runoff and sediment loss for Third Fork Creek for the storm of June 20, 1972

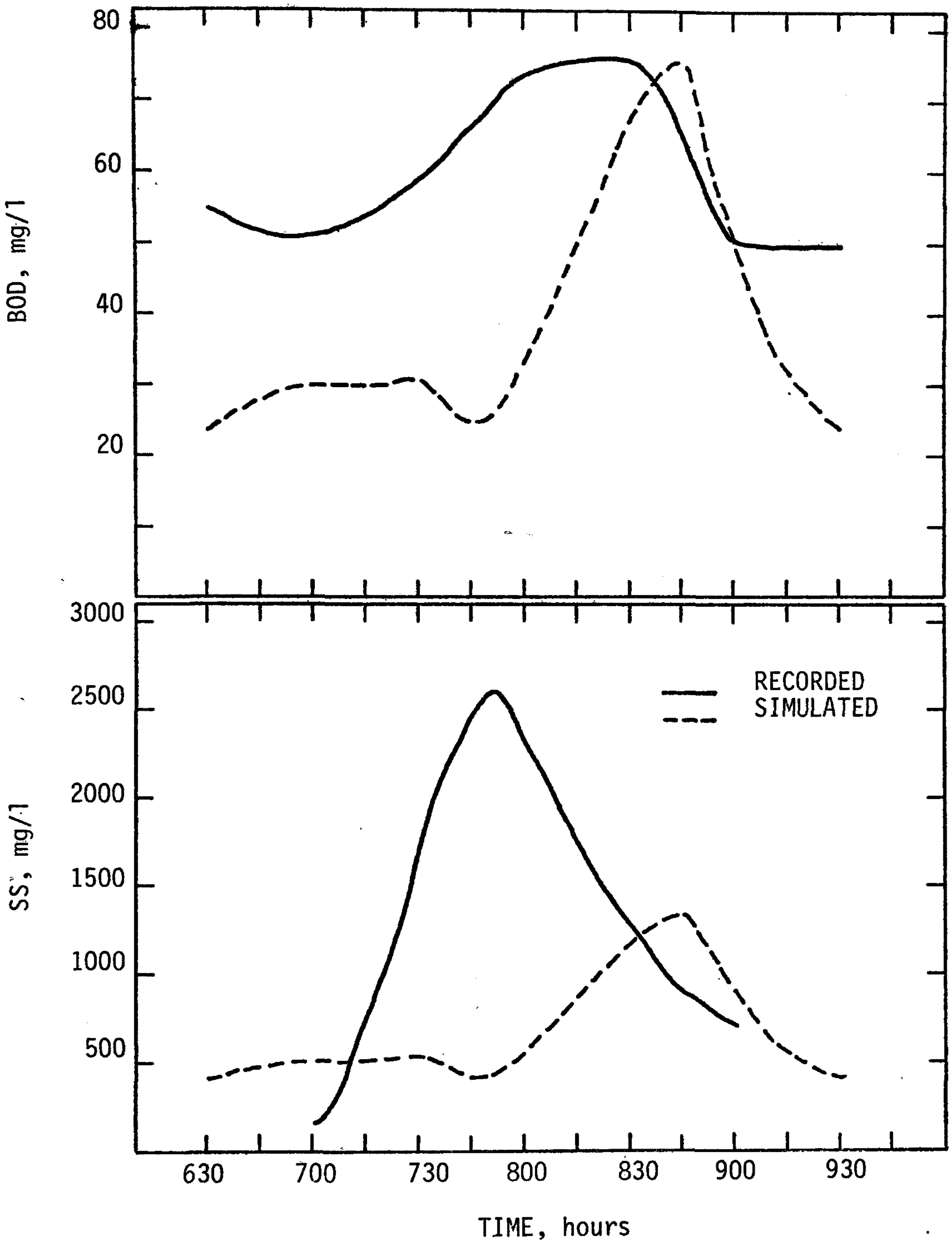

Figure 16. BOD and SS concentrations for Third Ford Creek for the storm of June 20, 1972.

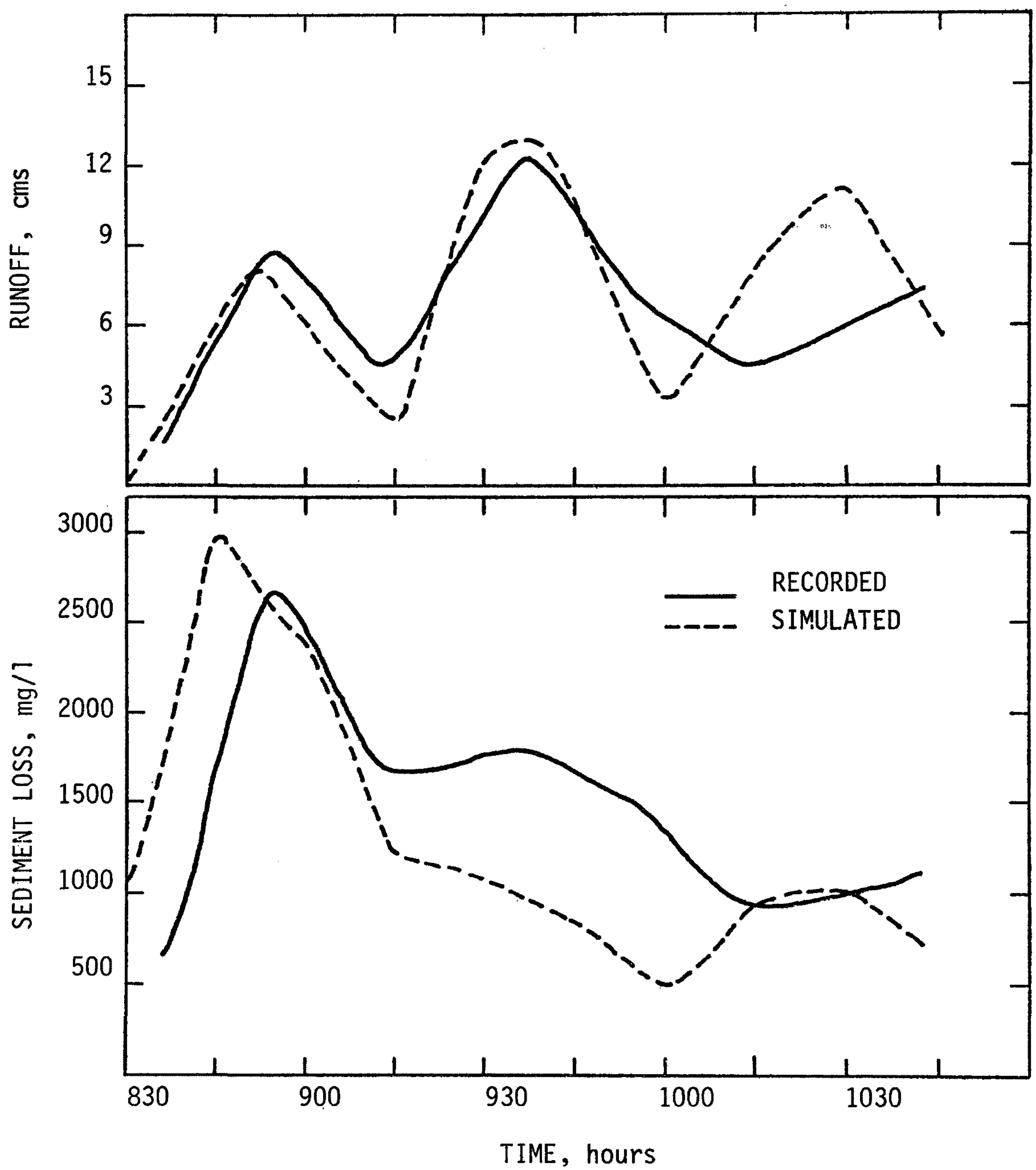

Figure 17. Runoff and sediment loss for Third Fork Creek for the storm of October 5, 1972.

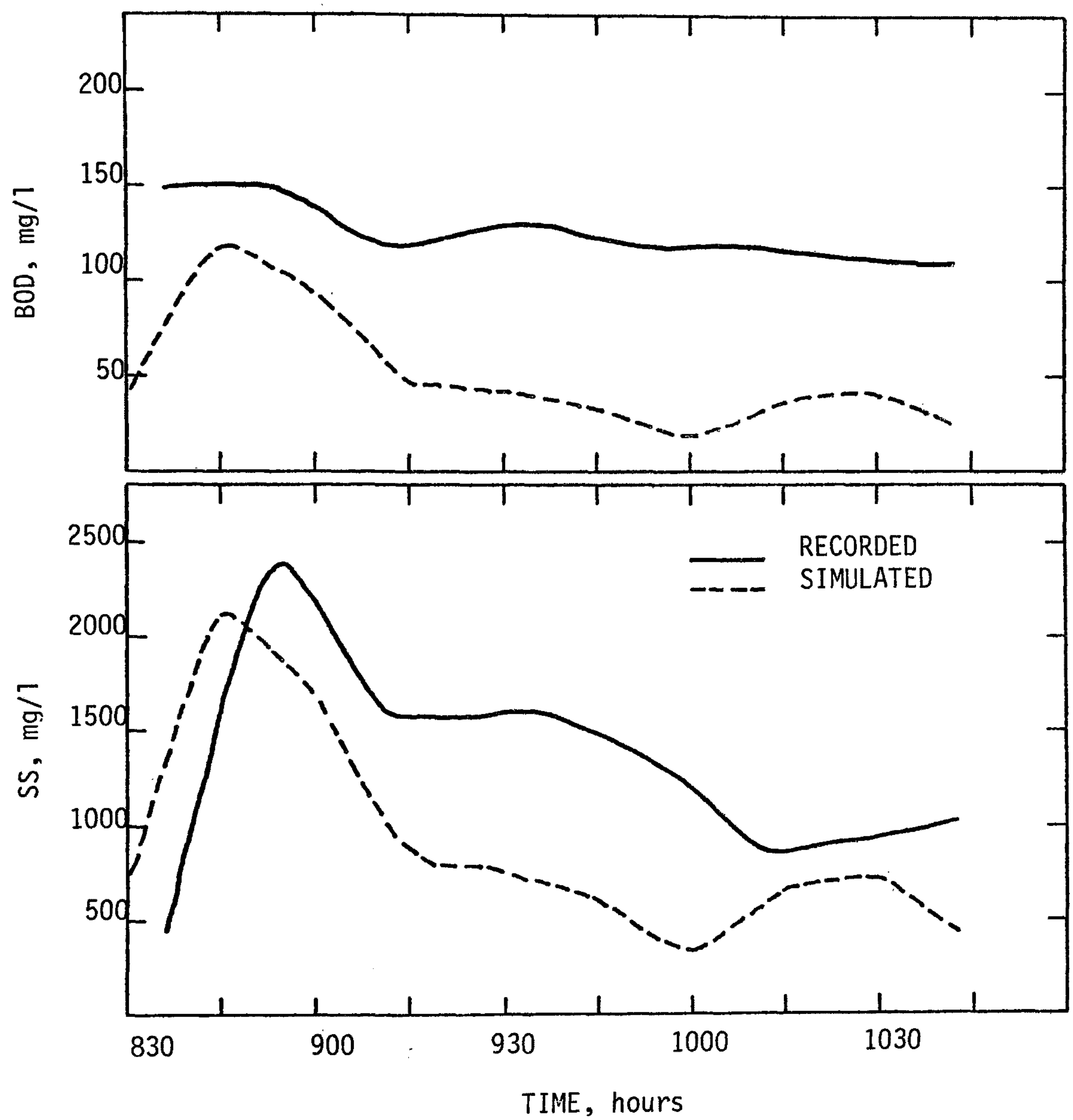

Figure 18. BOD and SS concentrations for Third Fork Creek for the storm of October 5, 1972.

surface runoff and increase low flows with little effect on total storm runoff volume. The hydrographs in Figures 11, 13, 15, and 17 partially demonstrate these effects. During initial calibration trials, the channel effects were more dramatic with extreme time variations in the flow rate. To partially compensate for these channel effects, the length of overland flow on impervious areas was increased because the impervious flow component provides the greatest time variation in runoff. In effect, this change delayed the impervious flow on the land surface and thus decreased the variability in the simulated hydrograph, improving the overall simulation. The results presented here are generally representative of the hydrologic simulation throughout the 18-month period and provide a reasonable basis for evaluating the nonpoint pollutant simulation methodology of the NPS Model.

Channel processes will also affect the time-variability of measured pollutant concentrations. In addition, erosion and deposition in the channel and accumulation of trash and debris can provide an additional source of pollutants within the channel system itself. The high sediment content of the runoff from Third Fork Creek and the pictures of debris cluttered channels indicate that the channel itself is a likely source of pollutants. The results of the sediment simulation (Figures 11, 12, 15, and 17) and the BOD and SS simulation (Figures 12, 14, 16, and 18) show greater pollutant concentration variability than in the measured values. Also, the recorded pollutant concentrations do not demonstrate the dependence on flow that is characteristic of nonpoint pollution. This is likely caused by dilution from baseflow and by mixing in the channel system. Although dilution would tend to decrease concentrations, erosion of channel sediment that likely occurs in Third Fork Creek could more than compensate for the dilution and results in high pollutant concentrations with less variability.

Pollutant mass removal in terms of mass per time interval is often more representative of nonpoint pollution than instantaneous concentrations. Mass removal of sediment, BOD, and SS is shown in Figure 19 for the storm of May 14, 1972. Since mass is obtained from the product of flow and concentration, the mass removal curves in Figure 19 clearly demonstrate the dependence on flow as a transport medium. For this reason, comparison of mass curves is the best method of evaluating simulated and recorded pollutant transport.

Despite the effects of channel processes discussed above, the results presented here indicate that estimates of nonpoint pollution from Third Fork Creek can be obtained with the NPS Model. Table 11 summarizes average simulated and recorded concentrations of sediment, BOD, and SS for selected storms on Third Fork Creek. Although discrepancies do exist, the overall agreement is sufficient to justify the use of the NPS Model as a tool for evaluation of nonpoint pollution problems.

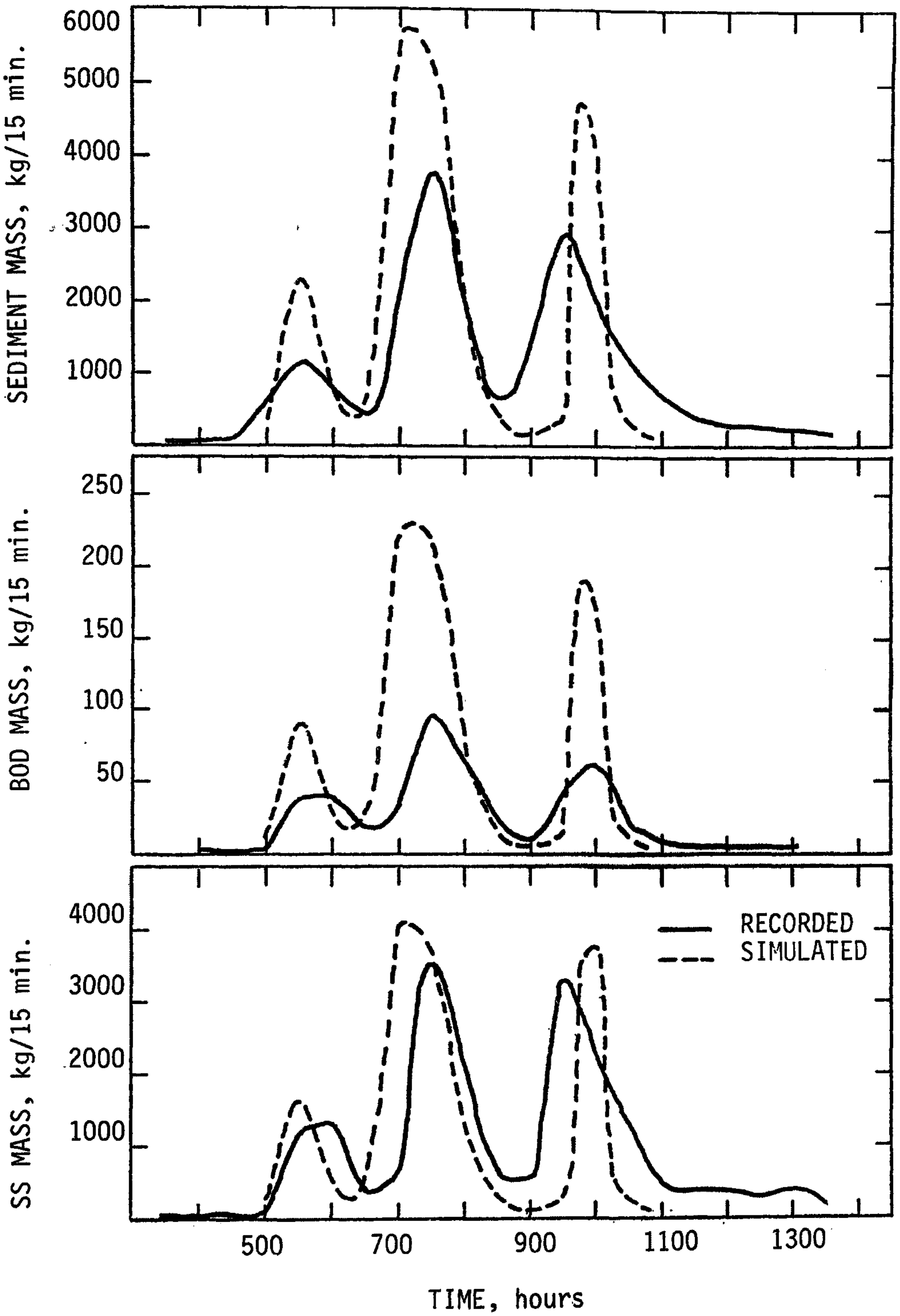

Figure 19. Pollutant mass transport for Third Fork Creek for the storm of May 14, 1972.

Table 11. SIMULATED AND RECORDED RUNOFF CHARACTERISTICS FOR SELECTED STORM EVENTS ON THIRD FORK CREEK[a]

Storm Date	Runoff				Average Water Quality					
	Mean Flow (cms)		Peak Flow (cms)		Sediment (mg/l)		BOD (mg/l)		SS (mg/l)	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
10/23/71	1.63	1.06	3.14	3.79	226	247	18.2	10.0	89	178
1/10/72	0.81	0.78	2.35	2.02	716	856	18.0	34.2	510	608
2/1/72	2.51	2.49	3.91	4.56	1676	1020	7.0	41.7	1459	724
2/12/72	0.94	1.25	2.15	2.13	1435	1059	NA	30.0	1396	752
2/18/72	0.58	0.67	0.82	1.05	NA	850	NA	34.0	1337	602
3/16/72	0.68	0.75	1.25	1.77	1042	940	30.5	38.0	826	670
3/31/72	0.52	0.65	1.16	1.47	1020	820	NA	33.0	945	583
4/12/72	1.17	1.38	2.07	2.79	1407	1260	22.7	50.0	1213	891
5/22/72	3.97	3.04	9.77	6.92	1583	640	NA	10.0	997	456
6/29/72	0.54	0.83	2.12	2.43	871	960	55.0	38.0	875	681
6/28/72	26.83	17.26	49.28	67.06	2460	1400	95.0	56.0	2397	991
7/17/72	2.27	2.06	3.54	4.76	3570	1570	80.5	63.0	2886	1116
7/31/72	2.29	0.78	3.94	1.59	2821	700	15.3	28.0	NA	495
9/17/72	6.63	9.32	10.34	28.49	2322	1303	37.9	49.1	NA	445
10/5/72	6.96	7.46	12.89	12.94	1487	946	128.6	37.9	1326	790

NA - Not Available

a. Recorded values may not equal those in Tables 7 and 8 because the comparisons were made on identical time periods that may or may not include the entire storm. Also, certain discrepancies were found between the storm event data and Colston's tables.

MANITOU WAY STORM DRAIN: MADISON, WISCONSIN

Watershed and Data Description

The Manitou Way Storm Drain is located in Madison, Wisconsin in the south central portion of the state. The 60-hectare watershed (147 acres) is contained within the Lake Wingra drainage basin as shown in Figure 20. Located on a low ridge with a northern exposure, the watershed drains in a northeasterly direction to Lake Wingra. Elevations in the upper portions are nearly constant at 300 meters (1000 feet) from which the land slopes steeply at approximately nine percent and then levels again near the basin outlet. As indicated by its name, the watershed is drained by storm sewers except for a few streets in the upper portions.

The continental climate of the region is only mildly affected by the proximity of the Great Lakes. Cold air masses descending from Canada keep winter temperatures quite low with frequent readings of -20 to -25 °C (-4 to -13 °F). An annual snowfall of 900 to 1000 millimeters (35 to 50 inches) results in snow-covered ground throughout most winters. Summers are moderate with temperatures reaching 32 °C (90 °F) six to eight days per year. Mean annual precipitation is approximately 760 millimeters (30 inches). The wettest period is generally in the spring when rainfall and snowmelt combine to produce frequent flooding. Thunderstorms are prevalent during the summer with an average of 40 storms per year.

The Manitou Way Storm Drain watershed is primarily a residential area of upper and middle class homes. The area is well-established with some houses more than 20 years old; there is little new construction in the watershed. Small portions of the eastern topographic divide are contained within an arboretum. The impervious portion of the watershed, including streets, rooftops, driveways and sidewalks, is about 27 percent of the watershed area.

Table 12 summarizes the data used in applying and calibrating the NPS Model to the Manitou Way Storm Drain watershed. The major source of meteorologic data was published records for the Class A weather station at Madison Airport (Truax Field) located 13.5 kilometers (8.4 miles) northeast of Manitou Way. The only continuous precipitation record available was an hourly record at Madison Airport. These data were supplemented with a sporadic record from a gage (Nakoma) located adjacent to Manitou Way in order to obtain a more precise time definition of rainfall for events for which water quality data was

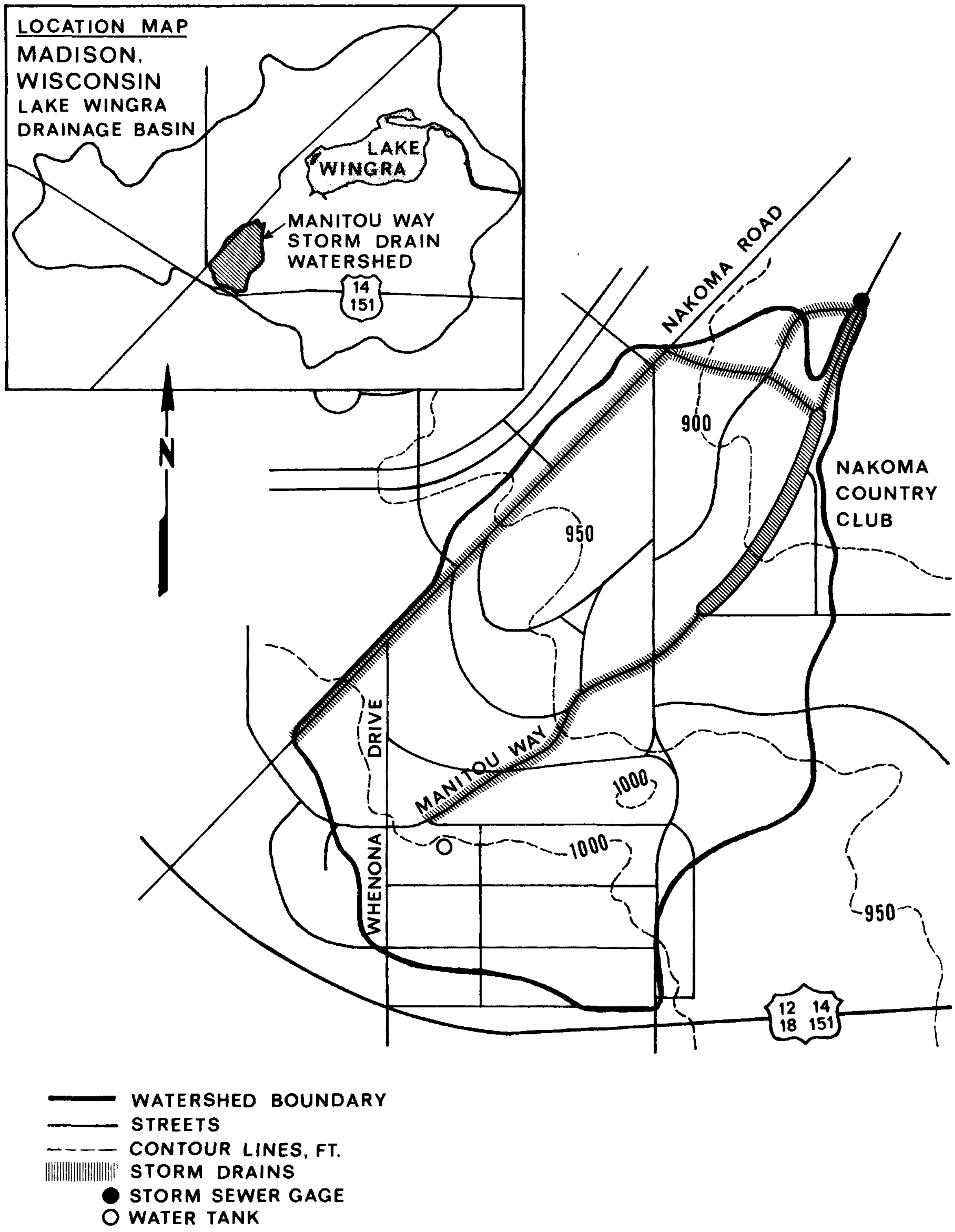

Figure 20. Manitou Way storm drain, Madison, Wisconsin

Table 12. DATA SUMMARY FOR MANITOU WAY

Type	Station Number	Location	Period of Record	Time Interval	Comment
Precipitation	-	Synthesis	9/70-9/72	15 min	see note a
	4961	Madison Airport		hourly	
	6165	Nakoma	4 storms	5 minute	These data were used for storms on which quality data were available.
Evaporation	4961	Madison Airport	9/70-9/72	daily	Computed from dewpoint temperature, wind, radiation, and air temperature by the Wisconsin Hydrologic Transport Model (70)
Max-min Air Temperature	4961	Madison Airport	9/70-9/72	daily	see above
Solar Radiation	4961	Madison Airport	9/70-9/72	daily	
Wind	4961	Madison Airport	9/70-9/72	daily	
Streamflow	05429040	Manitou Way	10/70-9/72	daily	
Streamflow	05429040	Manitou Way	selected storm events	irregular intervals	Obtained from study by Kluesener (69)
Water Quality	05429040	Manitou Way	selected storm events	irregular intervals	Obtained from study by Kluesener (69)

a. Precipitation record was synthesized from hourly data at Madison Airport and supplemented for selected storm events with data from the Nakoma gage located adjacent to Manitou Way.

available. Storm hydrographs and water quality concentrations were obtained from a study by Kluesener (69, 71) on nutrient loadings to Lake Wingra. Although that study emphasized nutrient data, total solids measurements were included.

Calibration and Simulation Results

Monthly simulation results for Manitou Way are shown in Figure 21 and listed in Table 13. The final Model parameters are presented in Table 14. As with the Durham watershed, monthly runoff values were the only recorded continuous data available for comparison with simulation results. The Kluesener study (69), which provided the water quality data for Manitou Way, concentrated on the evaluation of nutrient runoff into Lake Wingra. Consequently, total phosphorus was chosen for simulation with the NPS Model in addition to sediment. The monthly simulated values for these constituents are contained in Figure 21 and Table 13. Simulation of nutrient runoff from both urban and agricultural lands with the NPS Model is presently underway in a continuing development effort.

Hydrologic calibration was initially performed for two years of data (October 1969-September 1971) to obtain a general water balance. Subsequent calibration efforts concentrated on the period from September 1970 to June 1971 to provide a sound basis for water quality calibration. The agreement between simulated and recorded monthly runoff values for this watershed is fair. The major discrepancies shown in Figure 21 are due to either unrepresentative rainfall or the effects of frozen ground conditions on infiltration. Since the only continuous precipitation record available was at Madison Airport, numerous instances occur where the airport gage does not record substantial thunderstorms occurring on the watershed. Obviously, runoff cannot be adequately simulated if the recorded rainfall does not indicate that which fell on the watershed. This is a common problem that is frequently important for small watersheds in thunderstorm-prone areas.

Frozen ground conditions tend to decrease infiltration and increase surface runoff from that which would be expected under unfrozen conditions. The snowmelt routine of the NPS Model attempts to decrease infiltration when frozen ground conditions occur, but the accurate quantitative representation of these effects is a research topic of current interest. Thus, winter runoff volumes tend to be undersimulated in areas where frozen ground occurs. The simulation results in Figure 21 partially indicate this effect. In areas with substantial and continuous snow accumulations, frozen ground is less significant and snow simulation is generally more accurate.

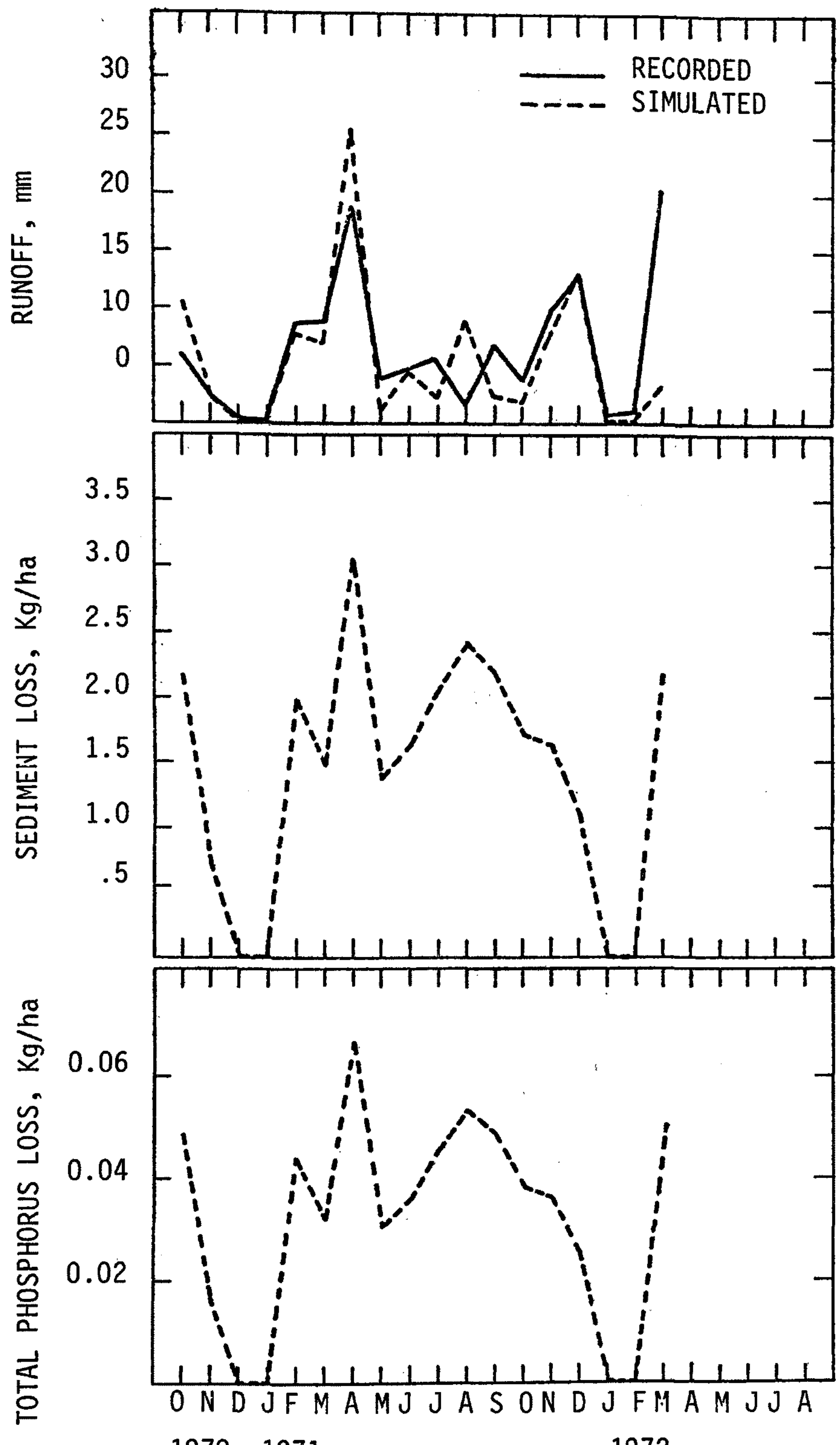

Figure 21. Monthly simulation results for the Manitou Way Watershed (October 1970 - March 1972)

Table 13. MONTHLY SIMULATION RESULTS FOR MANITOU WAY
(October 1970-March 1972)

Month	Runoff		Simulated Quality Parameters	
	Recorded (mm)	Simulated (mm)	Sediments (kg/ha)	Total Phosphorus (kg/ha)
1970				
October	6.1	10.7	2.20	0.047
November	2.3	2.3	0.73	0.016
December	0.2	0.0	0.00	0.000
1971				
January	0.0	0.0	0.00	0.000
February	8.6	7.9	2.03	0.044
March	8.9	7.1	1.52	0.032
April	19.0	25.6	2.63	0.057
May	3.8	1.0	1.47	0.031
June[a]	4.8	4.6	1.68	0.036
July	5.6	2.3	2.10	0.045
August	1.8	9.1	2.45	0.053
September	7.1	2.3	2.32	0.050
October	3.8	1.8	1.75	0.038
November	9.9	7.9	1.68	0.036
December	13.2	13.2	1.12	0.025
1972				
January	0.8	0.3	0.00	0.000
February	1.0	0.3	0.00	0.000
March	20.6	3.6	2.22	0.048
Total	117.5	100.0	25.92	0.558
Total for 1971	86.5	82.8	20.75	0.447

a. The recorded runoff for June 1971 was modified to account for a storm that was not recorded at the rain gage.

Table 14. NPS MODEL PARAMETERS FOR THE MANITOU WAY WATERSHED (English units)

HYDROLOGY

UZSN	0.75	NN	0.04	K1	1.05
LZSN	6.00	L	150	PETMUL	0.93
INFIL	0.10	SS	0.01	K3	0.40
INTER	3.5	NNI	0.15	EXPM	0.15
IRC	0.1	KI	700	K24L	1.0
AREA	147.2	SSI	0.01	KK24	0.99

Initial Conditions: September 2, 1970

UZS	0.75	LZS	6.00	SGW	0.50
PACK	0.0	DEPTH	0.0		

SNOW

RADCON	0.25	TSNOW	33.0	SCF	1.10
CCFAC	0.25	MPACK	0.10	WMUL	1.00
EVAPSN	0.60	DGM	0.001	F	0.50
ELDIF	0.0	IDNS	0.10	KUGI	8.0

SEDIMENT AND WATER QUALITY

JRER	3.0	JEIM	2.0
KRER	0.09	KEIM	0.35
JSER	1.90	TCF	12*1.0
KSER	0.30		

RESIDENTIAL LAND

ARFRAC	1.0			
IMPKO	0.1			
COVVEC = Jan	0.60	Jul	0.75	
Feb	0.63	Aug	0.80	
Mar	0.65	Sep	0.76	
Apr	0.67	Oct	0.71	
May	0.70	Nov	0.68	
Jan	0.73	Dec	0.64	

PMPVEC (total phosphorus)	2.15		
PMIVEC (total phosphorus)	2.15		
ACUP	1.20	REPER	0.05
ACUI	1.20	REIMP	0.08

Initial Conditions: September 2, 1970

SRERI	35
TSI	45

In spite of these problems, the monthly runoff volumes are reasonably simulated. When more accurate rainfall records are available, the simulation results are generally improved. Fifteen-minute rainfall values were available at the Nakoma gage adjacent to the Manitou Way watershed for the storm events of September 2, 1970 and November 9, 1970 shown in Figures 22 and 23, respectively. Except for timing variations, the simulated storm hydrographs accurately represent peak flows with some discrepancy in total storm volume. The simulated sediment and phosphorus storm concentrations reflect the deviations in simulated runoff, but they adequately approximate the recorded values. Further calibration efforts on additional data for both hydrology and water quality are recommended for this watershed. However, the close correlation between sediment and phosphorus concentrations indicates that sediment is an important indicator of nonpoint phosphorus pollution, verifying the general methodology in the NPS Model. Based on these calibrated results, it appears that the NPS Model can represent the nonpoint pollution characteristics of the Manitou Way watershed for the purpose of obtaining estimates of nonpoint pollutants. Additional calibration for other pollutants and verification through split-sample testing would be desirable when sufficient data are available.

SOUTH SEATTLE WATERSHED: SEATTLE, WASHINGTON

Watershed and Data Description

The South Seattle watershed contains the Benaroya Industrial Park and is located in the southern portion of the City of Seattle, Washington (see Figure 24). The drainage area is relatively flat (approximately 2 percent slopes) and covers 11.1 hectares (27.5 acres). A separate storm sewer system drains the watershed in a south-southwesterly direction. There are no known industrial discharges to the sewer system, and most of the roads are paved and include catch basins. However, only 50 percent of the roads have curbs to contain and direct the street surface runoff.

The Seattle area is subject to broad Pacific storm fronts approaching from the south and southwest during the wet winter-spring season and from the northwest during the summer. The climate is moderate due to the area's coastal location. Average daily temperatures are 3.3 °C (38 °F) and 18.3 °C (65 °F) in January and July, respectively. Mean annual precipitation is 990 millimeters (39 inches) at the Seattle-Tacoma Airport 11.5 kilometers (7.2 miles) south of the South Seattle watershed. However, topographic characteristics of the region cause a high degree of areal variability in the form and amount of

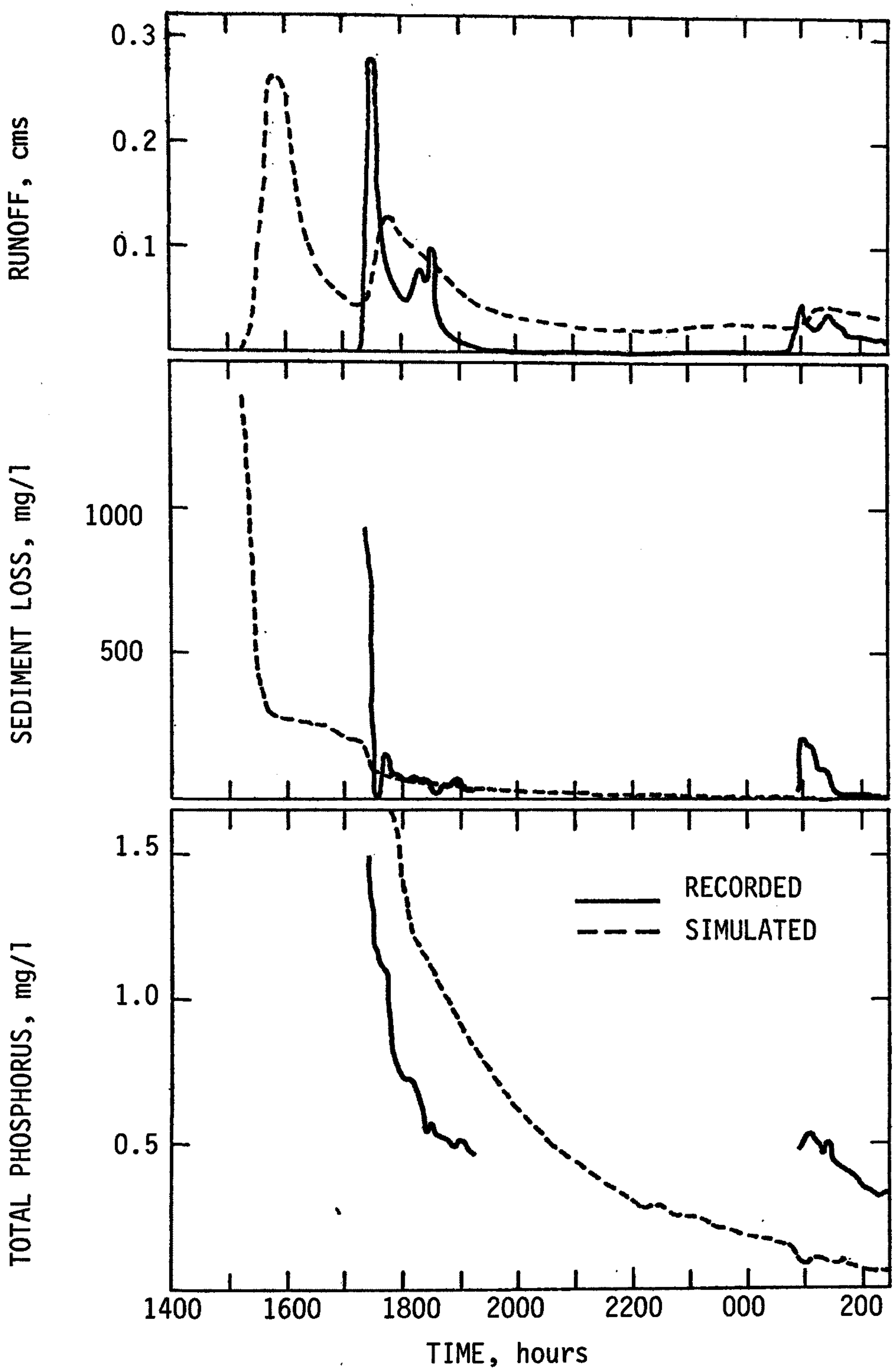

Figure 22. Runoff, sediment and phosphorus loss for the Manitou Way for the storm of September 2, 1970.

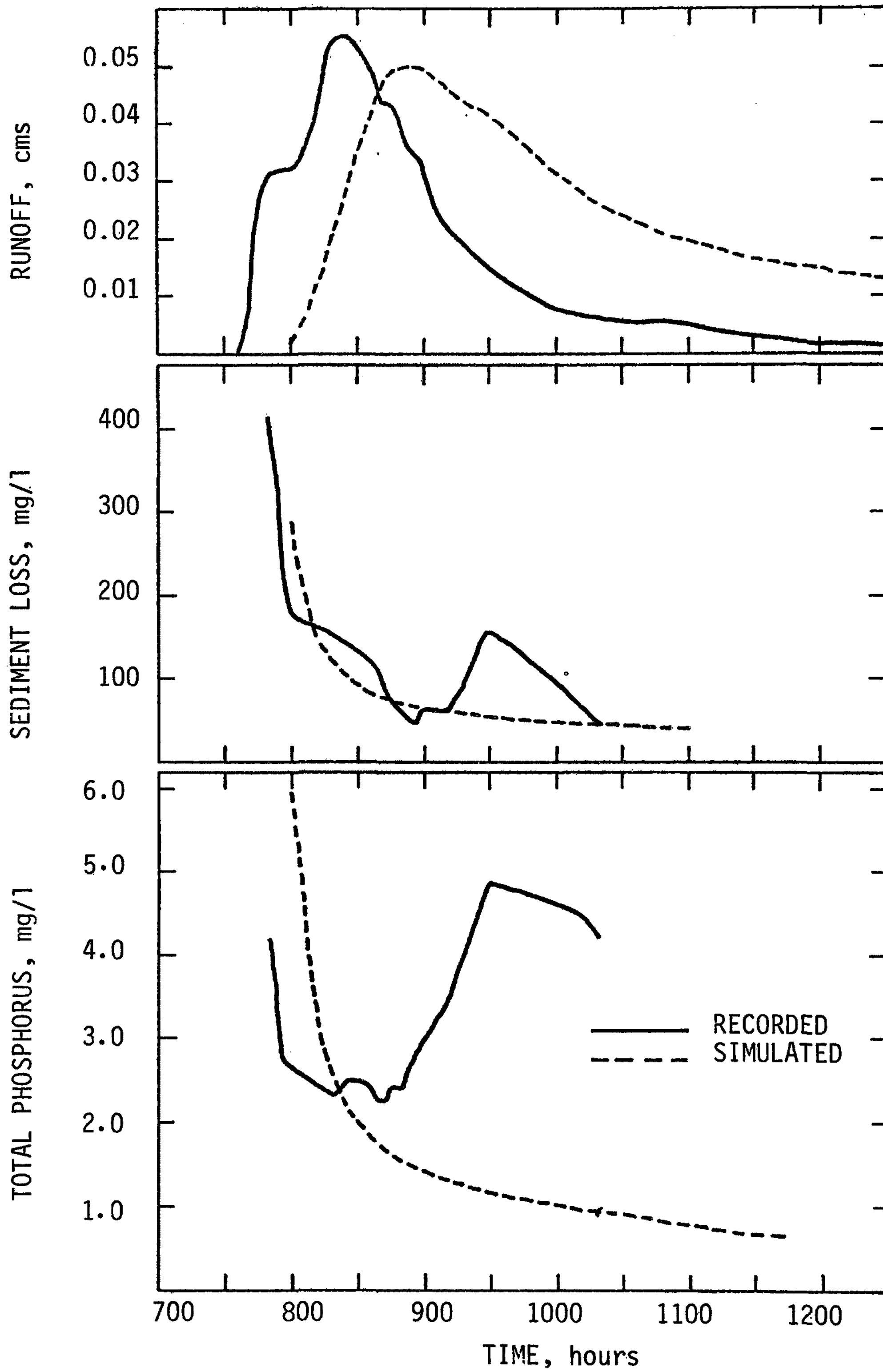

Figure 23. Runoff, sediment and phosphorus loss for Manitou Way for storm of November 9, 1970.

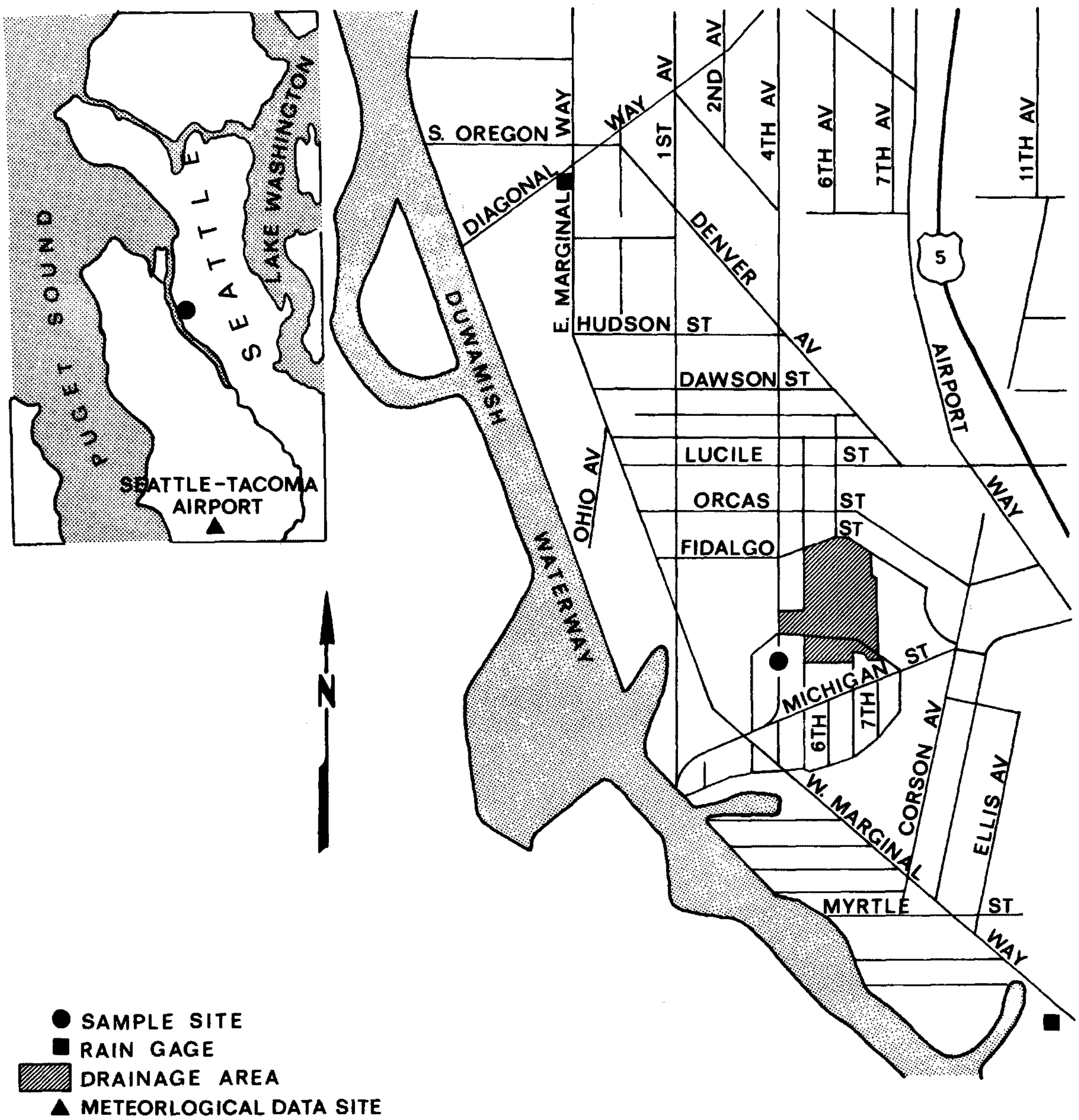

Figure 24. South Seattle watershed, Seattle, Washington

precipitation. At the South Seattle site snowfall averages less than 300 millimeters (12 inches) per year with little prolonged accumulation.

The land use of the South Seattle watershed is classified as light industrial. The area contains 30 to 35 manufacturing establishments ranging from a large foundry to a clothing factory, and including several freight handling companies. The industrial park was initiated in the late 1950's, but was not fully developed until the late 1960's. Approximately 60 percent of the watershed is impervious.

Table 15 summarizes the data used in the simulation of the South Seattle watershed. Precipitation data were obtained from two rain gages operated by the City of Seattle. One gage was located 1.6 kilometers northwest of the watershed at the Diagonal Avenue pump station, and the other 1.6 kilometers southwest of the basin at the East Marginal Way pump station (see Figure 24). Due to the small size of the drainage area and the areal variability in rainfall, it was necessary to combine data from the two stations into a single record. For each rainstorm the rainfall characteristics were chosen from one of the two stations depending on the magnitude and direction of travel of the storm. In each case, the rainfall record chosen logically appeared to produce the recorded flow at the watershed outlet.

Evaporation data were obtained from the Seattle Maple Leaf reservoir located 16 kilometers (10 miles) north of the watershed and were adjusted by monthly pan coefficients. Maximum and minimum daily air temperatures were obtained from the Seattle-Tacoma airport. This completed the required meteorologic data series since snow simulation was not performed.

Recorded streamflow and water quality data was available only for selected storm events in a nine-month period from a study sponsored by the Municipality of Metropolitan Seattle (METRO) (72). Flow data for 17 events and water quality data for five events from January to September 1973 was obtained for calibration purposes. Table 16 summarizes the extensive water quality measurements made on each of five storms on the South Seattle watershed.

Calibration and Simulation Results

Monthly simulation results are shown in Figure 25 and Table 17. The final NPS Model parameters are listed in Table 18. Unfortunately, no continuous recorded data for runoff or water quality were available for comparison with simulated values. This severely hampered both hydrologic and water quality calibration; thus, individual storm events

Table 15. DATA SUMMARY FOR THE SOUTH SEATTLE WATERSHED

Type	Station Number	Location	Period of Record	Time Interval	Comments
Precipitation		Synthesis	1/73-9/73	15-minute	see note a
		Diagonal Ave	1/73-9/73	5-minute	see Figure 24
		East Marginal Way	1/73-9/73	5-minute	see Figure 24
Evaporation		Seattle Maple Leaf Reservoir	1/73-12/73	semi-monthly	
Max-min air temperature	7473	Seattle-Tacoma Airport	1/73-9/73	daily	
Streamflow		South Seattle watershed	1/73-9/73	5-minute	for selected storms only
Water quality		South Seattle	3/73-9/73	15-minute	for 5 selected storms

a. Because of the areal variability in precipitation, the synthesized record was obtained from either the East Marginal Way or Diagonal Avenue gages, depending on the direction of travel of storm events.

Table 16. URBAN RUNOFF CHARACTERISTICS FOR SELECTED STORM EVENTS ON THE SOUTH SEATTLE WATERSHED

Parameter	Mean Concentrations					
	Mar 10	Mar 16	June 6	Aug 16	Sept 19	Mean
Temp. C°	8.1	9.4	18.0	20.1	18.2	14.8
pH	7.2	7.7	6.7	6.7	6.2	-
Cond. umho/cm	20	89	169	243	150	134
Turbidity, JTU	35	42	40	81	36	47
DO, mg/l	11.7	11.0	6.4	5.6	7.6	8.5
BOD, mg/l	2.9	5.1	38	36	14	19
COD, mg/l	7.0	56	147	156	111	95
Hexane Ext. mg/l	8.0	12	12	27	11	14
Chloride, mg/l	1.2	5.3	28	24	2.5	12.2
Sulfate, mg/l	3.6	12	30	41	44	26.1
Organic N, mg/l	0.55	0.90	1.8	2.9	2.5	1.7
Ammonia N, mg/l	0.12	0.24	0.25	0.57	0.42	0.32
Nitrite N, mg/l	0.02	0.07	0.06	0.07	0.06	0.06
Nitrate N, mg/l	0.24	0.29	0.90	1.6	1.1	0.83
Hydrolyzable P, mg/l	0.18	0.19	0.28	0.43	0.12	0.24
Ortho P, mg/l	0.03	0.05	0.10	0.14	0.08	0.08
Copper, mg/l	0.043	0.052	0.076	0.10	0.24	0.10
Lead, mg/l	0.10	0.27	0.13	0.50	0.27	0.25
Iron, mg/l	0.39	2.7	0.90	5.6	1.1	2.1
Mercury, mg/l	0.0004	0.0002	0.0006	0.0003	0.0003	0.0004
Chromium, mg/l	0.010	0.010	0.009	0.009	0.010	0.010
Cadmium, mg/l	0.005	0.005	0.004	0.006	0.004	0.005
Zinc, mg/l	0.08	0.30	0.53	0.70	0.53	0.43
Sett. Solids, mg/l	41	52	89	78	39	60
Susp. Solids, mg/l	63	91	100	109	39	80
TDS, mg/l	179	181	150	233	138	176
Total Coliform[a] org/100 mls	1000	360	5300	4200	14000	4200
Fecal Coliform[a] org/100 mls	360	20	20	30	180	30

[a]Medians

Source: Municipality of Metropolitan Seattle (81), p. 80

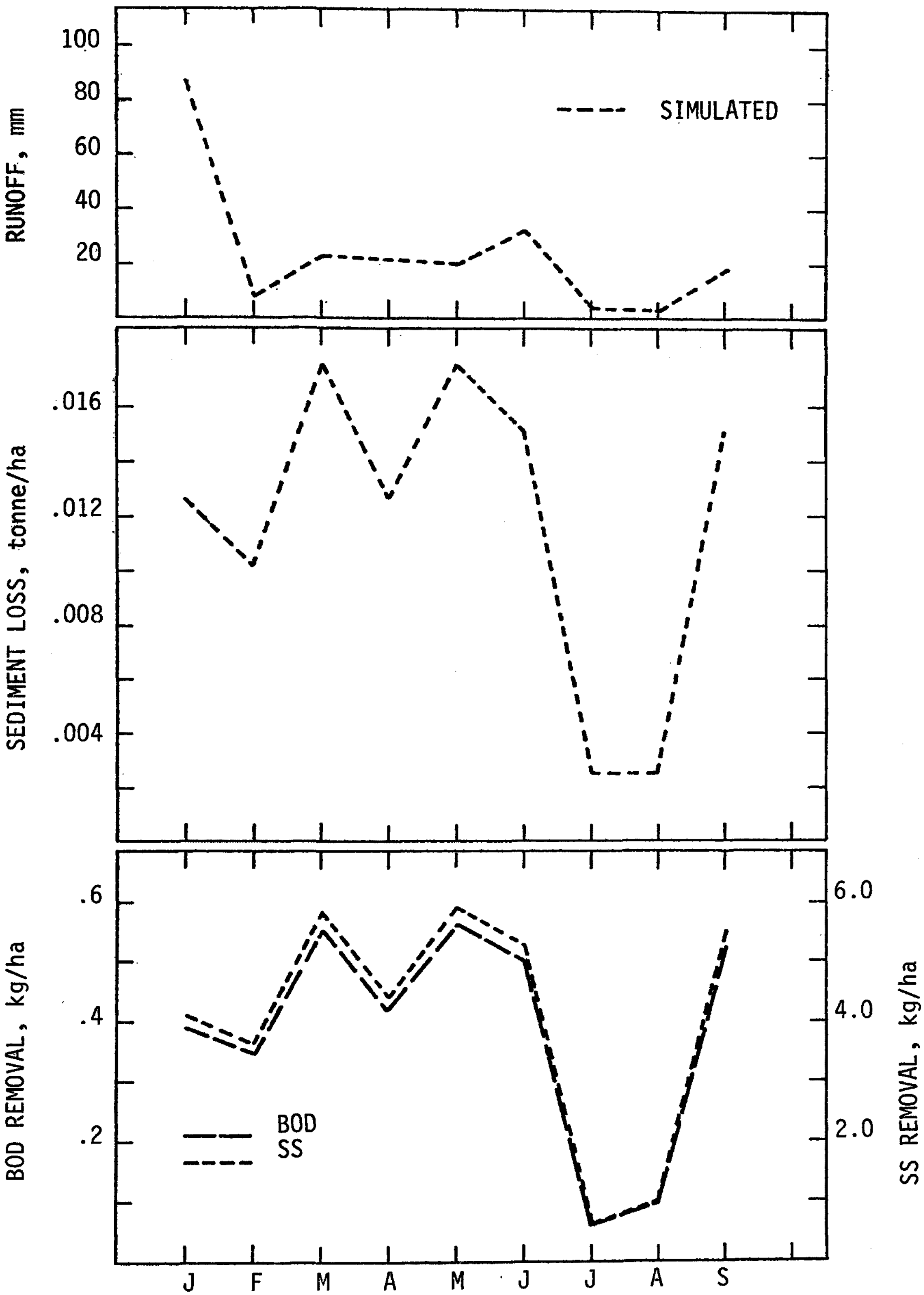

Figure 25. Monthly simulation results for the South Seattle Watershed (January - September 1973)

Table 17. MONTHLY SIMULATION RESULTS FOR SOUTH SEATTLE WATERSHED (January 1973-September 1973)

Month	Runoff (mm)	Sediment (kg/ha)	BOD (kg/ha)	SS (kg/ha)
January	87	10.6	0.38	4.02
February	8	9.4	0.34	3.57
March	23	15.2	0.55	5.77
April	22	11.4	0.41	4.33
May	21	15.3	0.55	5.81
June	33	13.7	0.49	5.22
July	4	1.7	0.06	0.63
August	4	2.7	0.10	1.03
September	19	14.4	0.52	5.47
Total	221	94.4	3.40	35.85

Table 18. NPS MODEL PARAMETER VALUES FOR THE SOUTH SEATTLE WATERSHED (English units)

HYDROLOGY

UZSN	0.90	NN	0.25	K1	1.0
LZSN	9.00	L	400	PETMUL	1.0
INFIL	0.04	SS	0.02	K3	0.30
INTER	3.00	NNI	0.15	EPXM	0.017
IRC	0.50	LI	600	K24L	0.0
AREA	27.5	SSI	0.02	KK24	0.99

Initial Conditions: January 1, 1973

UZS	1.24	LZS	12.44	SGW	0.0

SEDIMENT AND WATER QUALITY

JRER	2.0	JEIM	1.80
KRER	0.09	KEIM	0.27
JSER	1.80	TCF	12*1.15
KSER	0.27		

INDUSTRIAL LAND

ARFRAC	1.00	ACUP	1.5
IMPKO	0.60	ACUI	1.5
COVVEC	12*0.90	REPER	0.05
PMPVEC:	BOD 3.6	REIMP	0.08
	SS 38.0		
PMIVEC:	BOD 3.6		
	SS 38.0		

Initial Conditions: January 1, 1973

SRERI	0.0	TSI	0.0

were the only basis for calibration. Figures 26 through 31 present the simulation results for two storms on the South Seattle watershed occurring on March 10 and 16, 1973. Figures 26 and 29 show the runoff and sediment simulation for each storm, while Figures 27 and 30 present the BOD and SS results, and Figures 28 and 31 show the water temperature and DO simulation.

The simulated and recorded runoff agree quite well. However, the calibration should be considered tentative since continuous runoff data were not available to check the simulation of the monthly and annual water balance. Generally, large storm events are simulated considerably better than small events due to more uniform meteorologic conditions producing less areal variability in precipitation. Because of the high fraction of impervious area, the watershed is extremely responsive to rainfall. The data for simulation were obtained from gages 1.6 kilometers (1 mile) away from the watershed as described above. Consequently, differences in rainfall between the gage and the watershed are reflected in the simulation results. Moreover, the runoff simulation presented here is for the period of measured water quality data which were generally collected on the small events subject to greater areal variations. In spite of these problems, the simulated storm hydrographs shown in Figures 26 and 29 adequately represent the recorded data. The responsiveness of the watershed required that a small interception storage value (EPXM in Table 18) be used to accurately simulate small events. This is probably true for small watersheds with a high percentage of impervious area as often occurs in commercial and industrial areas. The water quality constituents, sediment, BOD, and SS are reasonably well simulated as shown in Figures 26, 27, 29, and 30 for the individual storm events. Sediment is more accurately reproduced due to the number of calibration parameters available to represent the sediment producing characteristics of the watershed. However, the simulations of BOD and SS are quite good; thus, validating the use of sediment as a pollutant indicator. Calibration of the sediment accumulation rates and the pollutant potency factors for impervious areas were of prime importance on the South Seattle watershed because of the predominance of impervious areas as pollutant sources in this watershed.

The South Seattle watershed provided an opportunity to evaluate the simulation of water temperature and dissolved oxygen. Initial trials indicated that the temperature of surface runoff can vary considerably from the existing air temperature at the time of runoff. Consequently, monthly temperature correction factors were introduced to allow adjustment of the simulated water temperature to account for special characteristics of the watershed. Dissolved oxygen is simulated by assuming saturation at the simulated water temperature. The results shown in Figures 28 and 31 indicate that the use of temperature

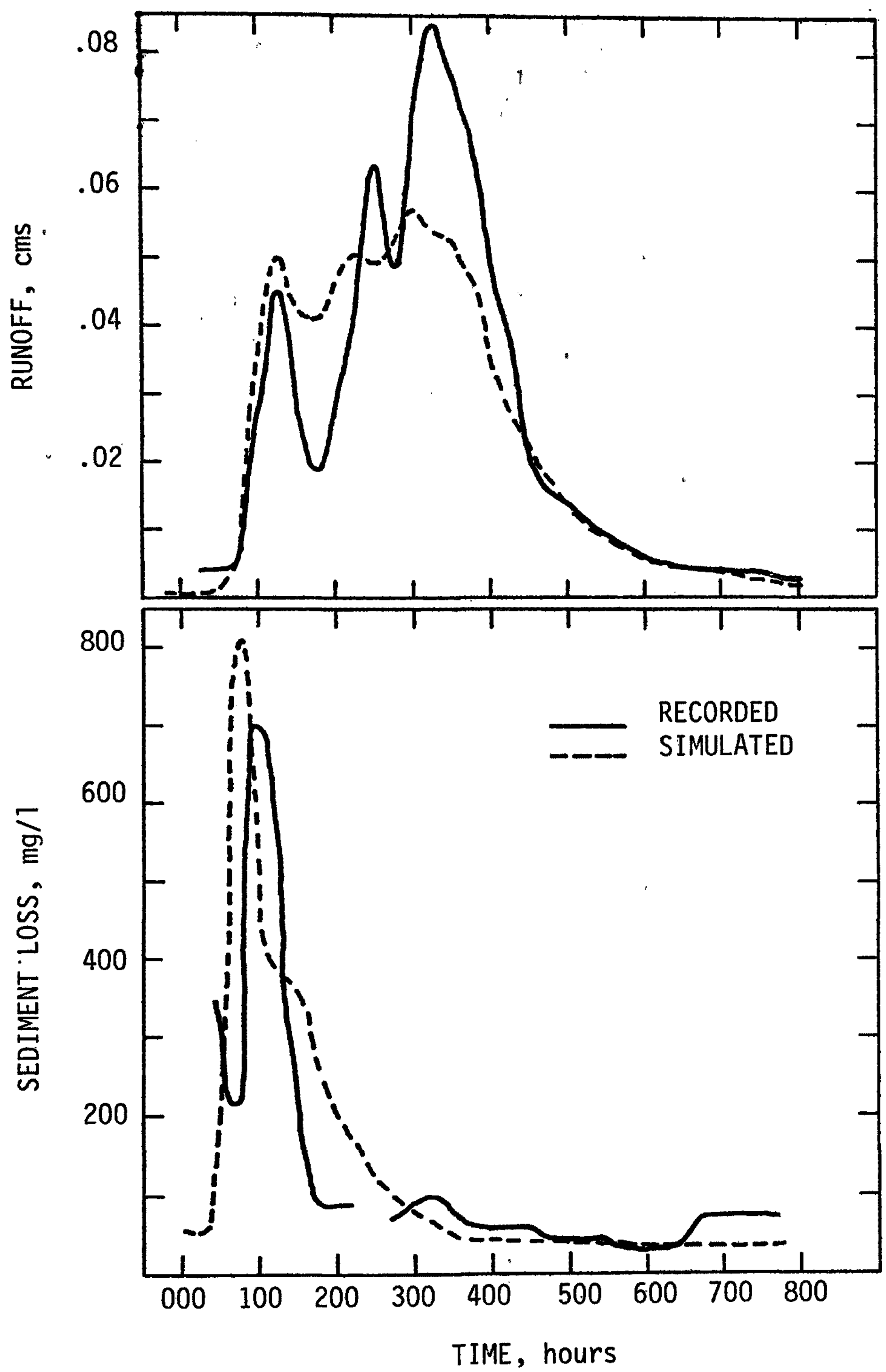

Figure 26. Runoff and sediment loss for the South Seattle Watershed for the storm of March 10, 1973.

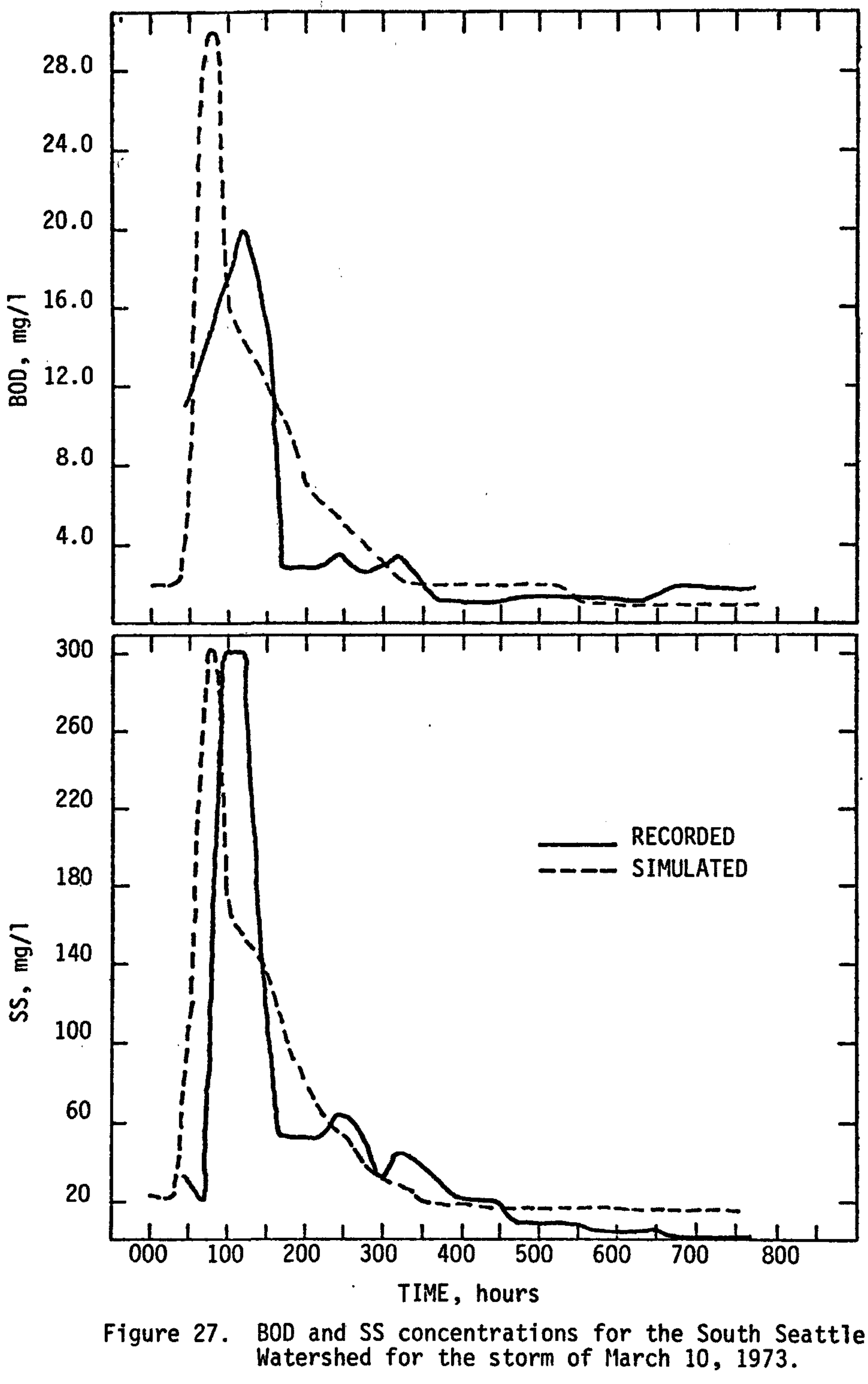

Figure 27. BOD and SS concentrations for the South Seattle Watershed for the storm of March 10, 1973.

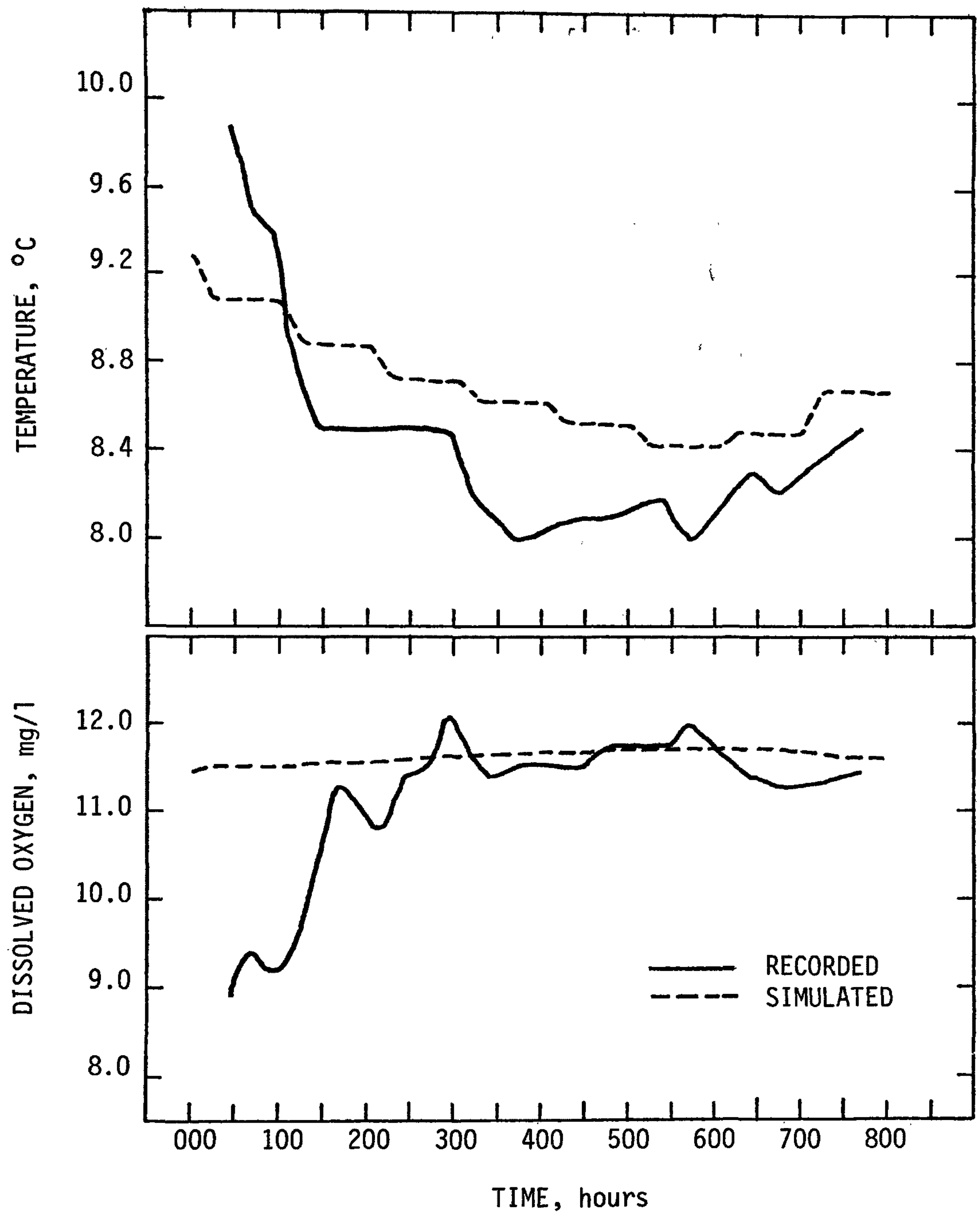

Figure 28. Water temperature and dissolved oxygen for the South Seattle Watershed for the storm of March 10, 1973.

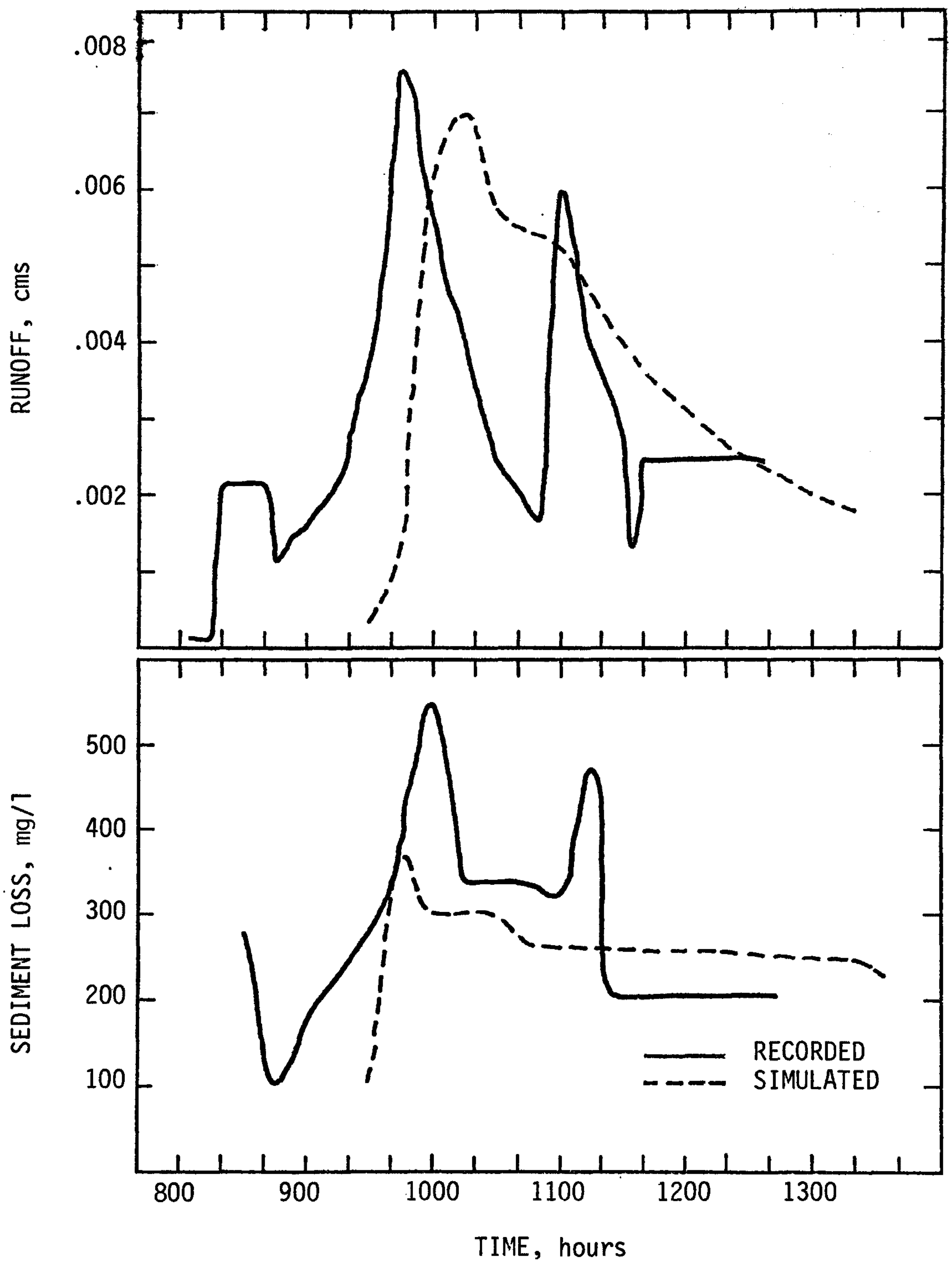

Figure 29. Runoff and sediment loss for the South Seattle Watershed for the storm of March 16, 1973.

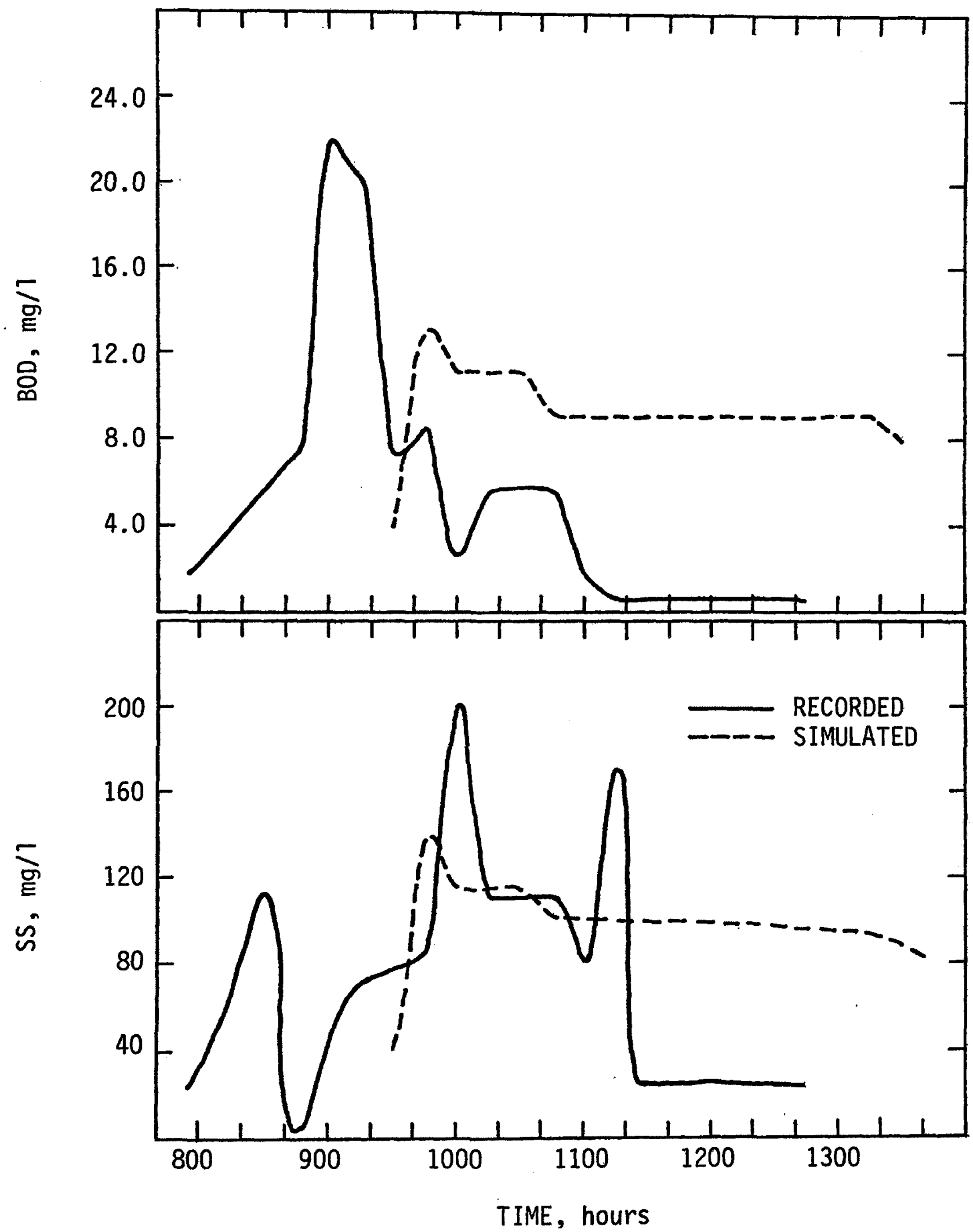

Figure 30. BOD and SS concentrations for the South Seattle Watershed for the storm of March 16, 1973.

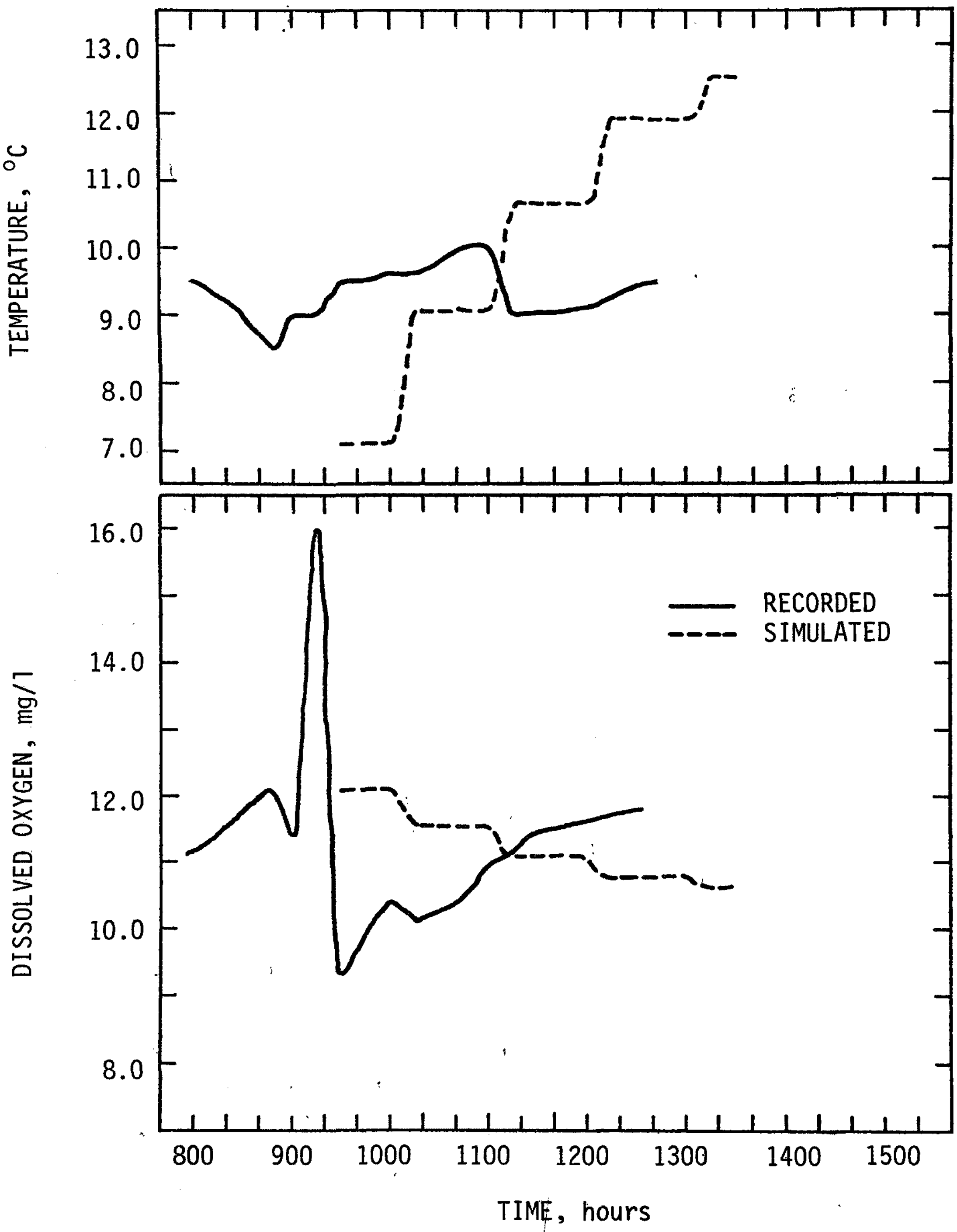

Figure 31. Water temperature and dissolved oxygen for the South Seattle Watershed for the Storm of March 16, 1973.

correction factors and the assumption of DO saturation can be used to estimate these water quality constituents in surface runoff from a watershed. However, significant variations are possible and calibration of the correction factors is mandatory.

Table 19 lists the mean simulated and recorded values of the water quality constituents for the events on the South Seattle watershed. Except for discrepancies in certain storms, results are relatively good; they indicate that the NPS Model can be calibrated to represent nonpoint pollutant production from this watershed.

CONCLUSIONS

This section has presented the results of testing the NPS Model on watersheds in Durham, North Carolina; Madison, Wisconsin; and Seattle, Washington. The emphasis has been on the demonstration of the ability to sufficiently calibrate the Model to represent the nonpoint pollutant characteristics of the watersheds. Total verification of the NPS Model could not be performed because of insufficient water quality data. Verification refers to the ability of a model to represent data other than that on which the model is calibrated. However, the hydrologic methodology of the NPS Model has been verified in past studies. The sediment and nonpoint pollutant simulation methodology is partially verified by the results on the Durham watershed; not all storms were used in calibration yet the NPS Model adequately represented the recorded data throughout the period of record. In continuous simulation parameters are not modified to simulate each storm separately; a single set of parameters is used for the entire simulation period. Also, the entire flexibility of the NPS Model was not completely utilized due to the lack of time and funds for extensive calibration efforts on each of the watersheds. Further work would have employed the feature of monthly variations in accumulation rates, removal rates, and potency factors to more accurately represent seasonal characteristics of nonpoint pollution. The results presented here were obtained from preliminary calibration using only annual values for these parameters.

In summary, the following conclusions are derived from the simulation experience with the NPS Model and the results presented here:

(1) The Nonpoint Source Pollutant Loading (NPS) Model can simulate land surface contributions of nonpoint pollutants from a variety of land uses. Model testing on three urban watersheds, comprised of residential, commercial, industrial, and open land, indicated good agreement between recorded and simulated hydrology and pollutant washoff.

Table 19. SIMULATED AND RECORDED URBAN RUNOFF CHARACTERISTICS FOR SELECTED STORMS ON THE SOUTH SEATTLE WATERSHED[a]

Storm Date	Runoff Characteristics				Average Water Quality Characteristics									
	Mean Flow (cms x 10)		Peak Flow		Temperature (°C)		DO (mg/l)		Sediment (mg/l)		BOD (mg/l)		SS (mg/l)	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
3/10/73	3.20	2.24	8.07	5.72	8.5	8.7	11.0	11.6	165	128	5.4	6.2	60.0	46.0
3/16/73	0.34	0.34	0.74	0.68	9.3	10.2	11.3	11.3	238	278	6.4	9.2	81.3	98.8
3/18-19/73	1.42	1.47	1.25	7.45										
4/18/73	0.88	0.91	5.15	4.56										
6/6/73	0.48	0.76	1.44	1.70	18.0	20.3	6.5	9.0	344	413	34.0	15.0	94.6	157.1
6/12/73	0.74	1.13	3.79	6.23										
6/25-26/73	0.99	1.53	7.42	5.21										
8/16/73	0.06	0.14	0.14	0.20	20.2	19.9	5.9	8.8	380	220	31.5	7.8	94.9	83.6
9/13/73	4.50	0.79	6.32	1.93	18.0	19.7	7.3	8.8	280	438	15.6	15.4	80.7	165.7

a. Recorded average water quality concentrations may not equal those in Table 16 because comparisons were made on identical time periods that may or may not include the entire storm.

(2) The hydrologic methodology of the NPS Model has been extensively applied, tested, and verified on numerous watersheds of varying size across the country. Simulation results were good on the watersheds tested in this study, and similar accuracy can be generally expected in other areas.

(3) Sediment and sedimentlike material can be used as an indicator of the land surface contributions of many nonpoint pollutants. Thus, specification of the pollutant strength, or potency, of sediment in conjunction with the simulation of sediment yield from pervious and impervious areas provides a workable methodology for simulating nonpoint pollution. The NPS Model algorithms are based on this concept. Although the simulated pollutants in this study were limited to sediment, biochemical oxygen demand, and suspended solids, the methodology is applicable to most insoluble and partially-soluble pollutants including many nutrient forms, heavy metals, organic matter, etc. However, highly soluble pollutants may demonstrate significant deviation from the simulated values.

(4) The NPS Model provides estimates of the total land surface loading to water bodies for various nonpoint source pollutants. Since the Model does not simulate channel processes, comparison of simulated and recorded values should be performed on watersheds less than 250 to 500 hectares (1 to 2 square miles) in order to avoid the effects of channel processes on the recorded flow and water quality. Size limit will vary with climatic, topographic, and hydrologic characteristics. Whenever channel processes appear to be significant, the output from the NPS Model should be input to a model that simulates stream processes before simulated and recorded values are compared.

(5) Due to incomplete quantitative descriptions of the processes controlling nonpoint pollution, calibration of certain Model parameters by comparing simulated and recorded values is a necessary step when applying the NPS Model to a watershed. Although all parameters can be estimated from available physical, topographic, hydrologic, and water quality information, calibration is needed to insure representation of the processes occurring on the particular watershed.

(6) The NPS Model can provide long-term continuous information on nonpoint pollution that can be used to establish the probability and frequency of occurrence of pollutant loadings under various land use configurations. Thus, when properly calibrated, the NPS Model can supplement available nonpoint pollution information and provide a tool for evaluating the water quality impact of land use and policy decisions.

SECTION IX

MODEL USE AND RECOMMENDATIONS

With adequate calibration and verification, the NPS Model can be used effectively in the analysis of nonpoint source pollution problems in both urban and rural areas. Typical problems for which the NPS Model may be applied include:

(1) expected changes in pollutant loadings from urbanization
(2) long-range pollutant loadings to water bodies under existing conditions
(3) the effects of construction activities on nonpoint pollution
(4) general impact of land use changes on nonpoint pollution
(5) evaluation of mulching, netting, and other land cover methods to reduce surface erosion and nonpoint pollution

Perhaps the most contemporary issue of concern for which the NPS Model can be utilized is the evaluation of nonpoint pollution problems as required by the Federal Water Pollution Control Act Amendments of 1972. The guidelines issued by the U.S. Environmental Protection Agency (6) for nonpoint pollution evaluation include the following formula:

$$N = (Q + S + D) - (P + I) \qquad (24)$$

where
N = Quantity (mass) of nonpoint source pollutants in terms of a given parameter, under a given design flow condition
Q = Quantity of pollutants in the water leaving the test area
S = Quantity of settlement and precipitation of pollutants
D = Quantity of decay of nonconservative pollutants
P = Quantity of pollutants discharged by point sources (assumed to be constant under a given design flow condition)
I = Quantity of pollutants in the water entering the test area

This formula calculates the total nonpoint pollutant loading under the design conditions. Although this study makes no statements concerning the validity or usability of Equation 24, the NPS Model can be used directly to estimate values of N, the nonpoint pollutant loading. Of course, the Model must be employed with the knowledge that the effects, either positive or negative, of stream channel processes are ignored. However, once calibration and verification have been completed, the Model can be reasonably applied to larger areas surrounding the calibrated watershed. The simulated values will be estimates of the nonpoint pollutant loadings from the various land uses in the larger area. In many situations, the NPS Model can be applied to watersheds that have hydrologic, topographic, climatic, and land use characteristics similar to the calibrated watershed. When used with caution, the Model can provide estimates in this manner for nonpoint pollutant loadings from similar areas.

The basic advantage of the NPS Model is the ability to provide continuous and long-term estimate of surface nonpoint pollution from various land uses. The manner in which this information is utilized depends on the specific problem and the proposed method of analysis. The validity of the information provided by the Model is a direct function of the extent of calibration and verification efforts on the particular watershed. If no calibration is performed, the best that can be expected is 'order-of-magnitude' estimates of annual or seasonal pollutant loadings. On the other hand, calibration and verification of the NPS Model can result in relatively reliable loading values on both a short-term and long-term basis.

In summary, wise use of the NPS Model requires an understanding of the processes being simulated, their representation in the Model, and the effects of certain important Model parameters. Study of the algorithm descriptions and the User Manual in Appendix A will provide the potential user with sufficient background to develop proficiency with the Model. To promote the use, application, and further refinement of the NPS Model, the following recommendations are extended:

(1) Application of the NPS Model to watersheds across the country is the primary need at this time. Although the Model has been tested on three watersheds, further application is required before it will be acceptable as a general and a reliable model. These applications will provide additional information on parameter evaluation under varying climatic, edaphic, hydrologic, and land use conditions, and may expose areas requiring further development and refinement in the simulation methodology.

(2) The application and use of the NPS Model as a tool for evaluating the impact of land use policy on the generation of nonpoint pollutants should be demonstrated. This could be done in conjunction with local planning agencies who might assist in Model

application, benefit from simulation results, and have access to the NPS Model for continuing use in the planning process. Such a project would demonstrate the utility of the NPS Model in a real-world setting.

(3) To promote use of the NPS Model, user workshops and seminars should be held to acquaint potential users with the operation, application, and data needs of the Model. In addition, a central users' clearinghouse could be initiated to (a) provide assistance to users with special problems, (b) recommend possible sources of data, (c) categorize and collect parameter information on calibrated watersheds, and (d) direct future improvements in the Model as indicated by the needs and comments of the users. The availability of these services would greatly facilitate, expand, and promote the use of the NPS Model.

(4) Further research and development of the NPS Model should be directed to the following topics:

(a) development of computer programs to further assist user application, such as: plotting and statistical analyses routines; data handing and management programs; and self-calibration and parameter optimization procedures.

(b) testing and application of the NPS Model on agricultural, construction, and silvicultural areas to examine special problems and pollutants associated with these land use activities.

(c) development of a stream simulation model to accept output from the NPS Model and perform the necessary flow and pollutant simulation for in-stream processes. Such a model would help eliminate the watershed size limitation of the NPS Model.

(d) continued research and refinement of the land surface pollutant washoff algorithms with examination of the behavior of highly soluble pollutants.

SECTION X

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SECTION XI

APPENDICES

APPENDIX A

NPS MODEL USER MANUAL

CONTENTS

A1. INTRODUCTION

The purpose of this User Manual is to provide a detailed description of the method of operation, application, and use of the Nonpoint Source Pollutant Loading (NPS) Model. Data requirements and sources, Model input and output, parameter definition and evaluation, and calibration procedures are discussed. This manual is not intended to replace the discussion of the modeling philosophy and algorithms presented in the body of this report. An understanding of the mechanisms of nonpoint pollution and the method of representation in the NPS Model is critical to successful application.

In general, the major steps involved in using the NPS Model are:

(1) data collection and analysis
(2) preparation of meteorologic data and Model input sequence
(3) parameter evaluation
(4) calibration
(5) production of needed information on nonpoint pollution.

The first three steps will often overlap as the input sequence of parameters and meteorologic data is being prepared for calibration trials. Section A2 describes the overall structure and operation of the NPS Model and was reproduced from Section IV of this report. The remaining sections provide the necessary information and guidelines for performing the steps in the application process. The final portion of this User Manual briefly discusses expected application and operation costs and computer requirements for the NPS Model.

A2. NPS MODEL STRUCTURE AND OPERATION

The NPS Model is a continuous simulation model that represents the generation of nonpoint pollutants from the land surface. The Model continuously simulates hydrologic processes (surface and subsurface), snow accumulation and melt, sediment generation, pollutant accumulation, and pollutant transport for any selected period of input meteorologic data. The NPS Model is called a 'pollutant loading' model because it estimates the total transport of pollutants from the land surface to a watercourse. It does not simulate channel processes that occur after the pollutants are in the stream. Thus, to simulate in-stream water quality in large watersheds, the NPS Model must interface with a stream simulation model that evaluates the impact of channel processes. The Model uses mathematical equations, or algorithms, that represent the physical processes important to nonpoint source pollution. Parameters within the algorithms allow the user to adjust the behavior of the Model to a specific watershed. Thus, the NPS Model should be calibrated whenever it is applied to a new watershed. Calibration is the process of adjusting parameter values until a good agreement between simulated and observed data is obtained. It allows the NPS Model to better represent the peculiar characteristics of the watershed being simulated. Fortunately, most of the NPS Model parameters are specified by physical watershed characteristics and do not require calibration. However, the importance of calibration should not be underestimated; it is a critical step in applying and using the NPS Model.

The NPS Model is composed of three major components: MAIN, LANDS, and QUAL. Figure 32 is an operational flowchart of the NPS Model demonstrating the sequence of computation and the relationships between the components. The Model operates sequentially reading parameter values and meteorologic data, performing computations in LANDS and QUAL, providing storm event information, and printing monthly and yearly summaries as it steps through the entire simulation period. MAIN, the master or executive routine, performs the tasks contained within the dashed portion of Figure 32. It reads Model parameters and meteorologic data, initializes variables, monitors the passage of time, calls the LANDS and QUAL subprograms, and prints monthly and yearly output summaries. LANDS simulates the hydrologic response of the watershed and the processes of snow accumulation and melt. The QUAL subprogram simulates erosion processes, sediment accumulation, and sediment and pollutant washoff from the land surface. During storm events, LANDS and QUAL operate on a 15-minute time interval. LANDS provides values of runoff from pervious and impervious areas while QUAL uses the runoff values and precipitation data to simulate the erosion and pollutant washoff processes. For nonstorm periods, LANDS uses a combination of 15-minute, hourly, and daily time intervals to simulate the

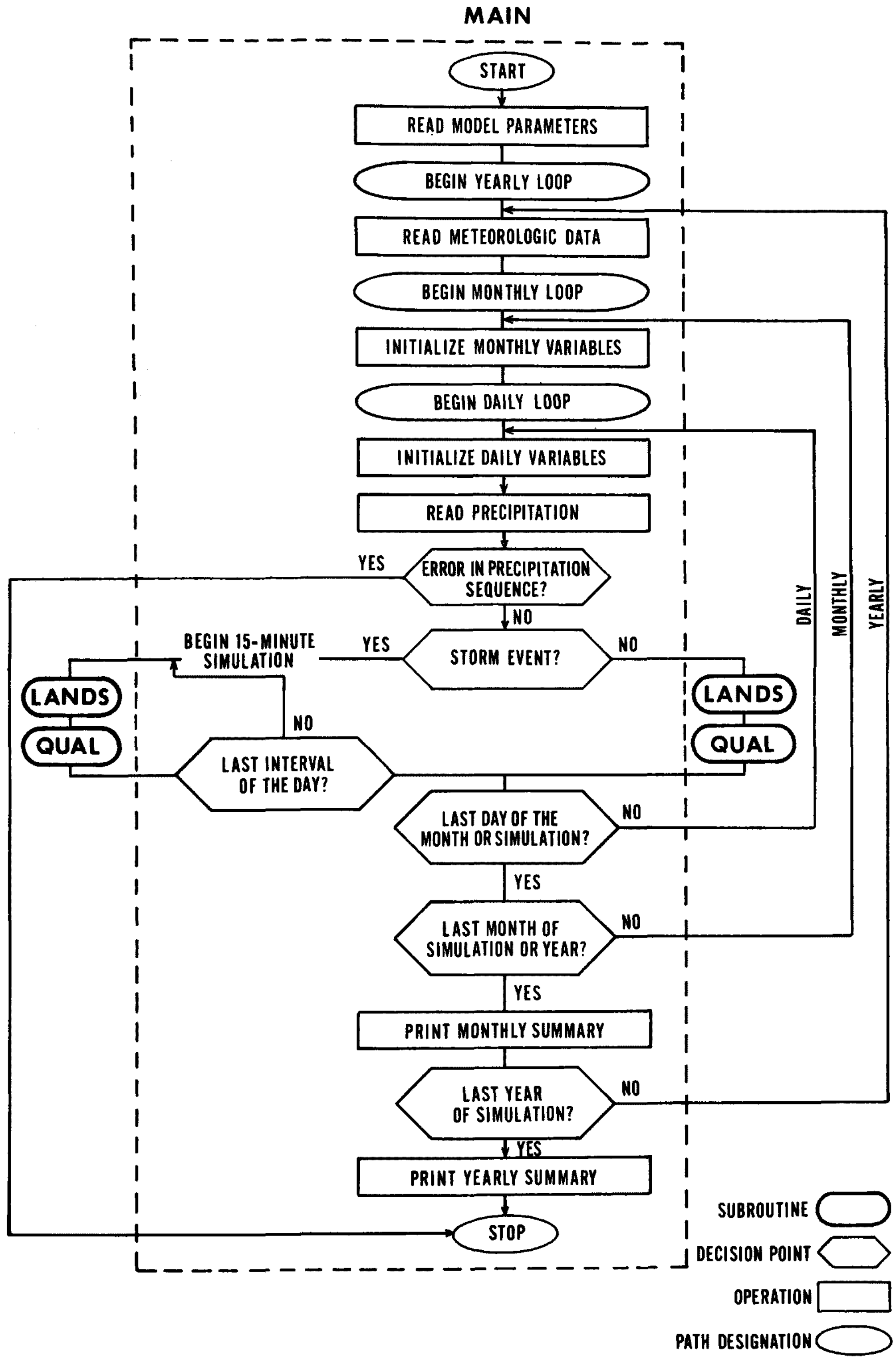

Figure 32. NPS model structure and operation

evapotranspiration and percolation processes that determine the soil moisture status of the watershed. Since nonpoint pollution from the land surface occurs only during storms, QUAL operates on a daily interval between storm events to estimate pollutant accumulations on the land surface that will be available for transport at the next storm event. Figure 32 indicates the individual operations of the MAIN program that occur on 15-minute, daily, monthly, and yearly intervals; these operations support the LANDS and QUAL simulation.

The NPS Model can simulate nonpoint pollution from a maximum of five different land uses in a single simulation run. The water quality constituents simulated include water temperature, dissolved oxygen (DO), sediment, and a maximum of five user-specified constituents. All are considered to be conservative due to the short resident time on the land surface that is characteristic of nonpoint pollution. Pollutant accumulation and removal on both pervious and impervious areas is simulated separately for each land use. The Model allows monthly variations in land cover, pollutant accumulation, and pollutant removal to provide the flexibility of simulating seasonally dependent nonpoint pollution problems, such as construction, winter street salting, leaf fall, etc. Although separate land uses are considered in the QUAL subprogram, LANDS combines all pervious and impervious areas into two groups for the hydrologic simulation regardless of land use. Pervious and impervious areas are simulated separately because of the differences in hydrologic response and because of the importance of impervious areas to nonpoint pollution in the urban environment.

Output from the NPS Model is available in various forms. During storm events, flow, water temperature, dissolved oxygen, pollutant concentration, and pollutant mass removal are printed for each 15-minute interval. Storm summaries are provided at the end of each event, and monthly and yearly summaries are printed. The yearly summaries include the mean, maximum, minimum, and standard deviation of each variable. To assist interfacing with other continuous models, the NPS Model includes the option to write the 15-minute output without summaries to a separate file (or output device) for later input to the stream model. In general, the NPS Model output is provided in different forms so that the information will be usable irrespective of the type of analysis being performed. Section A4 contains a full description of the output and options of the NPS Model.

A3. DATA REQUIREMENTS AND SOURCES

Data requirements for use on the NPS Model include those related to Model operation, parameter evaluation, and calibration. These requirements and possible sources of data are briefly discussed below. The input format and sequence of the meteorologic data are presented with Model I/O in Section A4.

Model Operation Data

The basic data for Model operation is the input meteorologic data series. Normal operation requires 15-minute or hourly precipitation, daily potential evapotranspiration, and daily maximum and minimum air temperature. If snowmelt simulation is performed, daily solar radiation and daily wind movement are also required. Since the NPS Model is a continuous simulation model, the period of record needed for each of these data series corresponds to the length of time for which simulation will be performed. To overcome the impact of initial hydrologic conditions (see Section A6) a minimum of one year should be simulated. The actual time period of simulation will depend on the information needed and the type of analysis being performed. There are no inherent limitations in the NPS Model on the length of the simulation period. Frequency analysis of the long-term output would provide valuable information on the probability of nonpoint pollution.

Parameter Evaluation Data

Data requirements for parameter evaluation pertain to NPS Model parameters that are evaluated largely from physical watershed characteristics. These include parameters related to topography, soil characteristics, land surface conditions, hydrologic characteristics, climate, land use, etc. The section on model parameters will describe each parameter individually and indicate methods of evaluation, references, and specific data sources. In general, the types of information needed for parameter evaluation include

topographic maps
soil maps and investigations
hydrologic/meteorologic studies
water quality studies
land use maps and studies

Any investigations related to the above topics for the watershed to be simulated should be collected and analyzed as a source of information for parameter evaluation.

Calibration Data

Calibration involves the adjustment of parameters to improve agreement between recorded and simulated information. For the NPS Model observed runoff and water quality data are required. In addition, if snow simulation is performed, recorded snow depth and water equivalent information are needed to evaluate the accuracy of the simulated values. Ideally, the observed data should be continuous to allow an accurate assessment of the continuous simulation produced by the NPS Model. In addition, the continuous data should extend for three years to obtain an adequate calibration of the parameters. However, data availability on most watersheds seldom approaches the ideal, especially for water quality. In such circumstances, calibration will be limited to comparisons with whatever data can be obtained.

Hydrologic calibration involves comparison of simulated and recorded runoff volumes and individual storm hydrographs for a calibration period of one to three years. The volume comparison can be made on a storm, daily, monthly, or yearly basis depending on the watershed area, the length of the calibration period, and the available data. Since the NPS Model simulates on 15-minute intervals, comparison of simulated and recorded storm hydrographs can be performed for intervals greater than 15 minutes; minor storms with durations less than 15 minutes would not provide sufficient hydrograph definition for a valid comparison. Thus, data for hydrologic calibration includes both continuous runoff volumes and selected storm hydrographs throughout the calibration period.

Water quality calibration for nonpoint pollution is analogous to hydrologic calibration; simulated pollutant mass removal on a storm, daily, monthly, or yearly basis, and individual storm pollutant graphs for selected storms are compared with recorded data. Since nonpoint pollution data is scarce, calibration is often reduced to comparison of grab-sample measurements or selected storm pollutant graphs with the simulated values. Actual data requirements for water quality calibration in the NPS Model are thus reduced to obtaining whatever water quality data are available for the watershed. Since the NPS Model simulates nonpoint pollution in terms of sediment, information on sediment (or Total Solids) yield and on the relationship between the individual pollutants and sediment would be the most pertinent.

Data Sources

To satisfy the data requirements of the NPS Model, a thorough search of all possible data sources is a necessary task in the initial phase of application. Many agencies at all governmental levels are involved in the collection and analysis of data relevant to nonpoint source pollution. Numerous federal agencies are active in monitoring and collection of environmental data. With regard to meteorologic data, the Environmental Date Service (formerly the Weather Bureau) provides a comprehensive network of meteorologic stations and regularly publishes the collected data. Table 20 lists publications of the Environmental Data Service where selected meteorologic data can be found. Most of these publications can be found in the libraries of colleges and universities, or regional offices of the Environmental Data Service. The EPA STORET and the USGS NASQAN data systems may be consulted for stream related water quality data. Table 21 presents a brief summary of selected federal agencies and data categories related to nonpoint pollution that may be available. Regional offices of the agencies listed in Table 21 should be contacted during the initial data collection phase in order to uncover any data available for the specific watershed being simulated.

Unfortunately, the large jurisdiction of federal agencies precludes data collection and monitoring on many small watersheds where the NPS Model would be applicable. Also, the emphasis of the federal agencies has been directed to major streams and river basins where water quality measurements include the effects of nonpoint pollution, point pollutant discharges, in-stream water use, and channel processes. Consequently, much of the available water quality data may not be directly comparable with the NPS Model simulation results; joint use of the NPS Model and a stream model may be needed.

Local, regional, and state agencies and possibly private firms located in the subject watershed may be the most important sources of pertinent data. Local agencies will often exhibit great interest in water quality because of direct and indirect impacts of pollution on their activities. The types of agencies that should be contacted include:

- planning commissions
- public works departments
- public utilities
- flood control districts
- water conservancy districts
- water resource and environmental agencies

Table 20. SELECTED METEOROLOGIC DATA PUBLISHED BY THE ENVIRONMENTAL DATA SERVICE[a]

Data Type		Publication[b]
Precipitation:	Daily	Climatological Data Hourly Precipitation Data
	Hourly	Hourly Precipitation Data Local Climatological Data (for selected cities)
Evaporation		Climatological Data
Max-min Air Temperature		Climatological Data Local Climatological Data (for selected cities)
Wind		Climatological Data Local Climatological Data
Solar Radiation		Climatological Data-National Summary
Snowfall and Snow Depth		Climatological Data

a. formerly the Weather Bureau
b. The National Climatic Data Center, Asheville, North Carolina can be contacted for assistance in locating published data and can provide data on magnetic tapes or punched cards.

Table 21. SELECTED FEDERAL AGENCIES AS POSSIBLE DATA SOURCES

Agency	Data Category					
	Climatologic[a]	Hydrologic	Water Quality	Land Use	Soil & Geology	Topographic
Environmental Protection Agency		*	**			
U.S. Geological Survey[b]		**	*		**	**
Forest Service	*	*	*	*	*	*
Bureau of Land Management			*	*		
Soil Conservation Service	*	*		*	**	*
Bureau of Mines			*	*		
Bureau of Reclamation	*	*	*		*	
Census Bureau				*		
National Park Service						*

*additional source
**major involvement
a. Publications of the Environmental Data Service listed in Table 20 are a major source of climatological data.
b. "Water Resources Data" is an annual publication of the USGS for each state. It provides data streamflow values at all USGS sites in the state. Also, regional offices of the USGS can often provide bi-hourly storm hydrographs for selected events.

Planning commissions and public works departments can be a source of land use, soils, and topographic data. Public utilities, flood control districts, and water conservancy districts will often establish meteorologic stations and monitor streamflow and water quality. State water resource and environmental departments are usually active in projects and investigations of water resources and water quality in the state. All agencies similar to those listed above should be consulted for data, special watershed studies, and other information to provide a sound base for application of the NPS Model.

A4. MODEL INPUT AND OUTPUT (I/O)

Model Input

The NPS Model accepts input of parameters and meteorologic data on a sequential basis in either English or metric units. Table 22 demonstrates the sequence of input data; a sample input listing is included in Appendix D. Input of the NPS Model parameters begins the sequence. Section A5 entitled "Model Parameters and Parameter Evaluations" defines and describes the parameter input sequence.

The NPS Model parameters are followed by the meteorologic data. All meteorologic data are input on a daily basis as a block of 31 lines (or cards) with 12 values in each line. Thus, the resulting 31 x 12 matrix corresponds to the 12 months of the year with a maximum of 31 days each. Table 23 demonstrates the format for the daily meteorologic data and Table 24 describes units and attributes. The only modification to the format in Table 23 is for daily max-min air temperature since two values are input for each day. In this case, the six spaces allowed for each daily value are divided in half. The first three spaces contain the maximum, and the second three spaces contain the minimum air temperature for the day. Table 25 indicates the format for precipitation data input on 15-minute or hourly intervals. For further clarification of these formats, see the sample input listing in Appendix D.

The Model operates continuously from the beginning to the end of the simulation period. To simplify input procedures and reduce computer storage requirements, the meteorologic data are input on a calendar year basis. Each block of meteorologic data indicated in Table 22 must contain all daily values for the portion of the calendar year to be simulated. Thus if the simulation period is July to February, the Model reads and stores all the daily meteorologic data for the July to December period. The Model then reads the precipitation data, on the 15-minute or hourly intervals, and performs the simulation day-by-day from July to December. When the month of December is completed, the Model reads the daily meteorologic data for January and February, and then continues stepping through the simulation period by reading the precipitation and performing the simulation day-by-day for the months of January and February. Thus the input data must be ordered on a calendar year basis to conform with the desired simulation period.

Model Output

The output obtained from the NPS Model includes the following:

Table 22. INPUT SEQUENCE FOR THE NPS MODEL

NPS Model Parameters	
Potential Evapotranspiration	1st Year
Max-Min Air Temperature	1st Year
Wind Movement	1st Year
Solar Radiation	1st Year
Precipitation	1st Year
Potential Evapotranspiration	2nd Year
Max-Min Air Temperature	2nd Year
Wind Movement	2nd Year
Solar Radiation	2nd Year
Precipitation	2nd Year
etc.	

Table 23. SAMPLE INPUT AND FORMAT FOR DAILY METEOROLOGIC DATA

	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
EVAP73	18	74	60	29	13	266	131	103	19	41	90	68	1
EVAP73	18	90	170	29	13	70	163	96	63	69	72	68	2
EVAP73	18	60	43	30	14	65	140	53	189	97	48	47	3
EVAP73	0	61	43	60	4	70	156	162	124	104	48	52	4
EVAP73	35	61	43	112	202	171	145	34	115	117	114	47	5
EVAP73	28	82	71	15	99	8	185	122	24	138	54	42	6
EVAP73	28	121	4	15	100	72	87	65	161	124	12	31	7
EVAP73	28	69	41	15	34	70	145	105	92	90	0	57	8
EVAP73	28	7	35	15	135	37	62	130	145	117	78	36	9
EVAP73	28	20	20	15	210	108	185	36	218	159	72	10	10
EVAP73	28	21	20	16	202	63	175	139	185	76	60	57	11
EVAP73	28	21	21	16	219	142	133	162	145	34	48	36	12
EVAP73	28	16	123	113	145	132	185	4	99	110	48	57	13
EVAP73	28	54	123	113	176	90	154	72	211	117	54	36	14
EVAP73	27	46	132	113	192	156	246	208	125	76	24	36	15
EVAP73	33	47	103	113	222	121	140	115	158	83	24	104	16
EVAP73	19	45	61	1	171	160	89	123	191	90	60	73	17
EVAP73	41	45	61	88	173	70	58	92	139	110	120	47	18
EVAP73	41	46	61	88	159	72	80	72	112	117	66	57	19
EVAP73	54	46	61	88	72	161	46	130	119	104	24	73	20
EVAP73	54	81	112	88	103	84	168	205	73	83	48	104	21
EVAP73	55	83	44	88	198	149	129	178	79	83	36	109	22
EVAP73	118	101	104	88	154	183	136	143	132	83	66	99	23
EVAP73	32	45	87	13	232	62	141	122	152	77	36	83	24
EVAP73	24	46	87	13	153	262	71	112	112	71	30	10	25
EVAP73	24	46	87	19	114	109	65	136	92	65	48	42	26
EVAP73	24	28	72	332	90	126	27	52	33	59	24	68	27
EVAP73	25	60	86	58	152	59	43	170	66	53	78	36	28
EVAP73	25		50	58	3	137	148	37	79	48	54	16	29
EVAP73	91		31	58	153	213	155	249	165	69	204	47	30
EVAP73	17		31		198		103	38		14		68	31
7	14	20	26	32	38	44	50	56	62	68	74	80	
	Column Number												

Notes:
1. Columns 1-7 are ignored. They can be used to identify the data.
2. All data are input in integer form.
3. Identical format for evaporation, wind, and solar radiation.
4. For Max-Min air temperature data, the six spaces allowed for each daily value (above) are divided in half; the first three spaces contain the maximum temperature, and the second three spaces contain the minimum temperature. See listing in Appendix D.

Table 24. METEOROLOGIC DATA INPUT SEQUENCE AND ATTRIBUTES[a]

Data	Interval	Units		Comments
		English	Metric	
Potential Evapotranspiration	Daily	in x 100	mm	Assumed equal to lake evaporation and lake evaporation = pan evaporation x pan coefficient
Max-Min Air Temperature	Daily	degrees F	degrees C	1. Caution: Time of observation determines whether the recorded values refer to the day of observation or the previous day.
Wind	Daily	miles/day	km/day	Required only for snow simulation.
Solar Radiation	Daily	langleys/ day	langleys/ day	1. Total incident solar radiation. 2. Required only for snow simulation. 3. 1 langley = 1 calorie/cm2
Precipitation	Hourly 15 minutes	in x 100 in x 100	mm mm	

a. All meteorologic data is input in integer form. Format specifications are described in Table 23.

Table 25. NPS MODEL PRECIPITATION INPUT DATA FORMAT

Column No.	Description and Format
1	Blank
2-7	Year, Month, Day (e.g. January 1, 1940 is 400101).
8	Card Number: 15 minute data- each card represents a 3-hour period Card #1 Midnight to 3:00 AM #2 3:00 AM to 6:00 AM #3 6:00 AM to 9:00 AM . . . #8 9:00 PM to Midnight All eight cards are required if rain occurred any time during the day. A card number of 9 signifies that no rain occurred during the entire day, and no other rainfall cards are required for that day. Hourly data--Each card represents a 12-hour period; thus, two (2) cards are required for each day when precipitation occurs. Card #1 is for the 12 AM hours and Card #2 is for the 12 PM hours. As with 15-minute, a card #9 indicates no precipitation occurred in that day.
9-80	Precipitation data (millimeters(00's of inches)). 15-minute intervals: 6 column per each 15-minutes in the 3-hour period of each card. Number must be right justified, i.e. number must end in the 6th column for the 15-minute period. Hourly intervals: 6 columns per each hourly interval, i.e. the hourly period still occupies 6 columns, but only two cards are needed for the entire day. Number must be right-adjusted.

Notes:
1. Appendix D contains a sample of input data.
2. At least one precipitation card is required for each day of simulation.
3. Blanks are interpreted as zeros by the Model: consequently, zeros do not need to be input.
4. Only integer values are allowed.

(1) output heading
(2) time interval output and storm summaries
(3) monthly and yearly summaries
(4) output to interface with other models (optional)

The heading of the NPS Model output provides a summary of the watershed characteristics, simulation run characteristics, and input parameters. Analysis of this information will uncover errors in specification of the input parameter values. Table 26 is an example of the output heading when average yearly values are used for the sediment accumulation and removal rates, and potency factors. Table 27 displays the output heading when monthly variations in these parameters are employed.

The time interval and storm summary output constitute the major portion of the output obtained from the NPS Model. Since the Model operates continuously on a 15-minute time step throughout the simulation period, output could be printed for every 15-minute interval. To prevent such voluminous output, an input parameter (HYMIN) allows the user to specify a minimum flow above which output is printed. Thus, output can be limited to only the major storms or the most significant portions of storm events. The type of output provided in each time interval depends on the mode of operation as specified by the input parameter, HYCAL. The modes of operation in the NPS Model are 'Calibration' (HYCAL=1,2) and 'Production' (HYCAL=3,4). The calibration mode can pertain to either hydrologic calibration (HYCAL=1) or sediment and water quality calibration (HYCAL=2). Table 28 provides an example of storm output for sediment and water quality calibration; hydrologic calibration output is identical except that the sediment and water quality constituent columns are blank because the quality computations are bypassed to save computer cost. The goal of the calibration output is to provide information on the sources of flow and pollutants within the watershed. Thus, calibration output indicates the contributions (flow and quality) from both pervious and impervious areas for each land use in the watershed; this information is valuable in the calibration process. At the end of each storm event, a storm summary is printed including the length and time of the storm, total and peak flow, and pollutant washoff characteristics as shown in Table 28.

Production run storm output (HYCAL=3) is presented in Table 29. Only total values of flow and quality from the entire watershed are printed. The individual storm summaries printed at the end of each storm event, and the sediment accumulation printed at the beginning of each storm are identical for both modes of operation, as shown in Tables 28 and 29.

Since snowmelt simulation is performed hourly, output is provided only during hydrologic calibration runs for each hour whenever snowmelt calculations are performed. Table 30 presents an example of daily

Table 26. NPS MODEL OUTPUT HEADING - ANNUAL WATER QUALITY PARAMETERS

NONPOINT SOURCE POLLUTANT LOADING MODEL
==

WATERSHED CHARACTERISTICS :

NAME SAMPLE INPUT DATA
NPS MODEL

TOTAL AREA (ACRE) 1069.00

LAND USE	% OF TOTAL	AREA (ACRES)	PERVIOUS (ACRES)	IMPERVIOUS (ACRES)	IMPERVIOUS (%)
OPEN AREA	10.0	106.90	101.55	5.34	5.00
RESID.AREA	60.0	641.40	525.95	115.45	18.00
COMMERCIAL	17.0	181.73	81.78	99.95	55.00
INDUSTRIAL	13.0	138.97	34.74	104.23	75.00

FRACTION OF IMPERVIOUS AREA 0.30

SIMULATION CHARACTERISTICS :

TYPE OF RUN	PRODUCTION (PRINTER OUTPUT ONLY)
DATE SIMULATION BEGINS	NOVEMBER 15, 1970
DATE SIMULATION ENDS	MARCH 31, 1971
INPUT PRECIPITATION TIME INTERVAL	60 MINUTES
SIMULATION TIME INTERVAL	15 MINUTES
IS SNOWMELT CONSIDERED ?	YES
INPUT UNITS	ENGLISH
OUTPUT UNITS	ENGLISH
MINIMUM FLOW FOR OUTPUT PER INTERVAL (CFS)	10.0000
NUMBER OF QUALITY INDICATORS ANALYZED	5
THE ANALYZED QUALITY INDICATORS	SEDIMENTS,DO,TEMP, BOD , SS ,

SUMMARY OF INPUT PARAMETERS :

LANDS	INTER = 2.000	IRC = 0.500	INFIL = 0.040
	NN = 0.300	L =300.000	SS = 0.100
	NNI = 0.150	LI =600.000	SSI = 0.100
	K1 = 1.400	PETMUL= 1.000	K3 = 0.250
	EPXM = 0.150	K24L = 0.0	KK24 = 0.990
	LZSN = 0.400	UZSN = 6.000	
SNOW	RADCON= 0.250	CCFAC = 0.250	EVAPSN= 0.600
	MELEV =800.000	ELDIF = 0.0	TSNOW = 33.000
	MPACK = 0.100	DGM = 0.001	WC = 0.030
	IDNS = 0.100	SCF = 1.100	WMUL = 1.000
	RMUL = 1.000	F = 0.500	KUGI = 8.000

Table 26 (continued). NPS MODEL OUTPUT HEADING - ANNUAL WATER QUALITY PARAMETERS

```
QUAL.            JRER  =  2.200    KRER  =  1.500
                 JSER  =  1.800    KSER  =  0.300
                 JEIM  =  1.800    KEIM  =  0.300

                  OPEN AREA        ACUP  = 30.000    ACUI  = 30.000
                 RESID.AREA        ACUP  = 70.000    ACUI  = 70.000
                 COMMERCIAL        ACUP  = 75.000    ACUI  = 75.000
                 INDUSTRIAL        ACUP  = 80.000    ACUI  = 80.000

                  OPEN AREA        RPER  =  0.050    RIMP  =  0.080
                 RESID.AREA        RPER  =  0.050    RIMP  =  0.080
                 COMMERCIAL        RPER  =  0.050    RIMP  =  0.080
                 INDUSTRIAL        RPER  =  0.050    RIMP  =  0.060
```

POTENCY FACTORS FOR PERVIOUS AREAS	OPEN AREA	RESID.AREA	COMMERCIAL	INDUSTRIAL
BOD	4.000	4.000	4.000	4.000
SS	71.000	71.000	71.000	71.000

POTENCY FACTORS FOR IMPERVIOUS AREAS	OPEN AREA	RESID.AREA	COMMERCIAL	INDUSTRIAL
BOD	4.000	4.000	4.000	4.000
SS	71.000	71.000	71.000	71.000

MONTHLY DISTRIBUTION	JAN	FEBR	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOVE	DECE
TEMP CORRECTION FACTOR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
- PERVIOUS LANDS -												
LAND COVER- OPEN AREA	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900
RESID.AREA	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950
COMMERCIAL	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900
INDUSTRIAL	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900

```
INITIAL CONDITIONS :

LANDS            UZS   =  0.0      LZS   =  2.250    SGW   =  1.000

SNOW             PACK  =  0.0      DEPTH =  0.0

QUAL              OPEN AREA        TS    =  106.000    SRER  = 1758.000
                 RESID.AREA        TS    =  248.000    SRER  = 1880.000
                 COMMERCIAL        TS    =  266.000    SRER  = 2658.000
                 INDUSTRIAL        TS    =  284.000    SRER  = 2758.000
```

Table 27. NPS MODEL OUTPUT HEADING - MONTHLY WATER QUALITY PARAMETERS

NONPOINT SOURCE POLLUTANT LOADING MODEL

WATERSHED CHARACTERISTICS :

NAME MONITOU WAY STORM DRAIN
MADISON, WISCONSIN

TOTAL AREA (ACRE) 147.20

LAND USE	% OF TOTAL	AREA (ACRES)	PERVIOUS (ACRES)	IMPERVIOUS (ACRES)	IMPERVIOUS (%)
RESID.AREA	100.0	147.20	132.48	14.72	10.00

FRACTION OF IMPERVIOUS AREA 0.10

SIMULATION CHARACTERISTICS :

TYPE OF RUN	PRODUCTION (PRINTER OUTPUT ONLY)
DATE SIMULATION BEGINS	SEPTMBER 2, 1970
DATE SIMULATION ENDS	MARCH 31, 1972
INPUT PRECIPITATION TIME INTERVAL	60 MINUTES
SIMULATION TIME INTERVAL	15 MINUTES
IS SNOWMELT CONSIDERED ?	YES
INPUT UNITS	ENGLISH
OUTPUT UNITS	ENGLISH
MINIMUM FLOW FOR OUTPUT PER INTERVAL (CFS)	0.0500
NUMBER OF QUALITY INDICATORS ANALYZED	4
THE ANALYZED QUALITY INDICATORS	SEDIMENTS,DO,TEMP, TOTAL-P ,

SUMMARY OF INPUT PARAMETERS :

LANDS	INTER = 3.500	IRC = 0.100	INFIL = 0.100
	NN = 0.400	L =150.000	SS = 0.010
	NNI = 0.150	LI =700.000	SSI = 0.010
	K1 = 1.050	PETMUL= 0.930	K3 = 0.400
	EPXM = 0.150	K24L = 1.000	KK24 = 1.000
	UZSN = 0.750	LZSN = 6.000	

Table 27 (continued). NPS MODEL OUTPUT HEADING - MONTHLY WATER QUALITY PARAMETERS

SNOW	RADCCM = 0.250	CCFAC = 0.250	EVAPSN = 0.600
	MELEV = 800.000	ELDIF = 0.0	TSNOW = 33.000
	MPACK = 0.100	DGM = 0.001	WC = 0.050
	IDNS = 0.100	SCF = 1.100	WMUL = 1.000
	RMUL = 1.000	F = 0.500	KUGI = 8.000
QUAL	JRER = 3.000	KRER = 0.090	
	JSER = 1.900	KSER = 0.300	
	JEIM = 2.000	KEIM = 0.350	

MONTHLY DISTRIBUTION	JAN	FEBR	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOVE	DECE
TEMP CORRECTION FACTOR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
- PERVIOUS LANDS -												
LAND COVER-RESID.AREA	0.600	0.630	0.650	0.670	0.700	0.730	0.750	0.860	0.760	0.710	0.680	0.640
ACCUMULATION RATES												
RESID.AREA	1.200	1.300	1.400	1.500	1.600	1.700	1.650	1.550	1.450	1.350	1.250	1.150
REMOVAL RATES												
RESID.AREA	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
POTENCY FACTORS FOR TOTAL-P												
RESID.AREA	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150
-IMPERVIOUS LANDS-												
ACCUMULATION RATES												
RESID.AREA	1.200	1.300	1.400	1.500	1.600	1.700	1.650	1.550	1.450	1.350	1.250	1.150
REMOVAL RATES												
RESID.AREA	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
POTENCY FACTORS FOR TOTAL-P												
RESID.AREA	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150	2.150

INITIAL CONDITIONS :

LANDS	UZS = 0.750	LZS = 6.000	SGW = 0.500
SNOW	PACK = 0.0	DEPTH = 0.0	
QUAL	RESID.AREA	TS = 45.000	SRER = 35.000

Table 28. CALIBRATION RUN OUTPUT FOR STORM EVENTS (Sediment and water quality calibration, HYCAL=2)

OUTPUT FOR STORM NO. 13 - OCTOBER 1971

ACCUMULATION OF DEPOSITS ON GROUND AT THE BEGINNING OF STORM,TONS/ACRE

LAND USE	WEIGHTED MEAN	PERVIOUS	IMPERVIOUS
AGRIC.AREA	0.700	0.737	0.000
RESID.AREA	0.723	0.864	0.081
COMMERCIAL	0.586	1.187	0.095
INDUSTRIAL	0.391	1.237	0.108
WEIGHTED MEAN	0.654	0.900	0.093

Q U A L I T Y   C O N S T I T U E N T S

DATE	TIME	FLOW CFS	TEMP (F)	DO(PPM)	SEDIMENTS (LB)	SEDIMENTS (GM/L)	BOD (LB)	BOD (GM/L)	SS (LB)	SS (GM/L)
OCT 23	5: 0	14.034	65.06	9.33	375.61	0.477	15.02	0.019	266.69	0.338

TOTAL FLOW 14.034, CFS
IMPERV. FLOW 11.363, CFS
PRECIPITATION 0.0 , IN

COVER	LAND USE	SEDIMENTS (LB)	BOD (LB)	SS (LB)
	AGRIC.AREA	0.49	0.020	0.347
COVER= 0.90	PERV.	0.0	0.0	0.0
	IMPERV.*	0.49	0.020	0.347
	RESID.AREA	135.50	5.420	96.203
COVER= 0.95	PERV.	0.0	0.0	0.0
	IMPERV.	135.50	5.420	96.203
	COMMERCIAL	117.31	4.692	83.287
COVER= 0.90	PERV.	0.0	0.0	0.0
	IMPERV.	117.31	4.692	83.287
	INDUSTRIAL	122.32	4.893	86.850
COVER= 0.90	PERV.	0.0	0.0	0.0
	IMPERV.	122.32	4.893	86.850

DATE	TIME	FLOW CFS	TEMP (F)	DO(PPM)	SEDIMENTS (LB)	SEDIMENTS (GM/L)	BOD (LB)	BOD (GM/L)	SS (LB)	SS (GM/L)
OCT 23	5:15	13.220	65.00	9.34	386.68	0.521	15.47	0.021	274.54	0.370

TOTAL FLOW 13.220, CFS
IMPERV. FLOW 10.560, CFS
PRECIPITATION 0.014, IN

COVER	LAND USE	SEDIMENTS (LB)	BOD (LB)	SS (LB)
	AGRIC.AREA	0.31	0.012	0.220
COVER= 0.90	PERV.	0.0	0.0	0.0
	IMPERV.*	0.31	0.012	0.220
	RESID.AREA	139.56	5.582	99.085
COVER= 0.95	PERV.	0.0	0.0	0.0
	IMPERV.	139.56	5.582	99.085
	COMMERCIAL	120.82	4.833	85.782
COVER= 0.90	PERV.	0.0	0.0	0.0
	IMPERV.	120.82	4.833	85.782
	INDUSTRIAL	125.99	5.040	89.452
COVER= 0.90	PERV.	0.0	0.0	0.0
	IMPERV.	125.99	5.040	89.452

Table 28 (continued). CALIBRATION RUN OUTPUT FOR STORM EVENTS
(Sediment and water quality calibration, HYCAL=2)

```
OCT 23   5:30    12.759 65.00     9.34    313.77    0.438    12.55    0.018  222.78    0.311

  TOTAL FLOW   12.759, CFS
 IMPERV. FLOW  10.064, CFS
PRECIPITATION   0.0  ,  IN

                        AGRIC.AREA          0.30              0.012             0.210
        COVER= 0.90          PERV.          0.0               0.0               0.0
                             IMPERV.*       0.30              0.012             0.210

                        RESID.AREA        113.23              4.529            80.393
        COVER= 0.95          PERV.          0.0               0.0               0.0
                             IMPERV.      113.23              4.529            80.393

                        COMMERCIAL         98.03              3.921            69.599
        COVER= 0.90          PERV.          0.0               0.0               0.0
                             IMPERV.       98.03              3.921            69.599

                        INDUSTRIAL        102.22              4.089            72.577
        COVER= 0.90          PERV.          0.0               0.0               0.0
                             IMPERV.      102.22              4.089            72.577


---------------------------

SUMMARY FOR STORM #  13

NUMBER OF TIME INTERVALS    3
STORM BEGINS      OCT 23   5: 0
STORM ENDS        OCT 23   5:45
TOTAL FLOW ( IN )        0.009
PEAK FLOW (CFS )        14.034
                                   SEDIMENTS            BOD               SS
TOTAL WASHOFF (TONS)                  0.54             0.022             0.382
MAX WASHOFF ( LB /15MIN)            386.68            15.467           274.540
MEAN CONCENTRATION (GM/L)             0.48             0.019             0.340
MAX CONCENTRATION (GM/L)              0.52             0.021             0.370
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```

Note: An asterisk (*) is printed beside the words 'PERV.' or 'IMPERV.' for each land use whenever the accumulated sediment is less than the overland flow sediment transport capacity.

Table 29. PRODUCTION RUN OUTPUT FOR STORM EVENTS (HYCAL = 3)

OUTPUT FOR STORM NO. 7 - JANUARY 1972

ACCUMULATION OF DEPOSITS ON GROUND AT THE BEGINNING OF STORM,TONS/ACRE

LAND USE	WEIGHTED MEAN	PERVIOUS	IMPERVIOUS
OPEN AREA	0.388	0.406	0.045
RESIC.AREA	0.662	0.747	0.275
COMMERCIAL	0.553	0.856	0.306
INDUSTRIAL	0.479	0.906	0.337
WEIGHTED MEAN	0.592	0.720	0.300

Q U A L I T Y   C O N S T I T U E N T S

DATE	TIME	FLOW CFS	TEMP (F)	DO(PPM)	SEDIMENTS (LB)	SEDIMENTS (GM/L)	BOD (LB)	BOD (GM/L)	SS (LB)	SS (GM/L)
JAN 13	4:30	12.343	45.22	12.04	575.07	0.830	23.00	0.033	408.30	0.589
JAN 13	4:45	44.323	45.22	12.04	2171.29	0.873	86.85	0.035	1541.62	0.620
JAN 13	5: 0	24.012	45.22	12.04	1091.90	0.810	43.68	0.032	775.25	0.575
JAN 13	5:15	18.373	45.00	12.08	633.72	0.614	25.35	0.025	449.94	0.436
JAN 13	5:30	12.121	45.00	12.08	305.36	0.449	12.21	0.018	216.80	0.319

SUMMARY FOR STORM # 7

NUMBER OF TIME INTERVALS 5
STORM BEGINS JAN 13 4:30
STORM ENDS JAN 13 5:45
TOTAL FLOW (IN) 0.026
PEAK FLOW (CFS) 44.323

	SEDIMENTS	BOD	SS
TOTAL WASHOFF (TONS)	2.39	0.09555	1.69595
MAX WASHOFF (LB /15MIN)	2171.29	86.85162	1541.61621
MEAN CONCENTRATION (GM/L)	0.72	0.02860	0.50773
MAX CONCENTRATION (GM/L)	0.87	0.03490	0.61954

---

snowmelt output that is printed in the last hour of each snow simulation day when the calibration option is specified. Table 31 defines the snowmelt output values shown in Table 30.

The monthly and yearly summaries are shown in Tables 32 and 33, respectively. These summaries are identical for both calibration and production modes of operation. The information provided in the monthly summary includes total values for hydrologic information; soil moisture storages and sediment accumulation at the end of the month; total sediment and pollutant washoff for pervious and impervious areas in each land use; and average storm values for temperature, dissolved oxygen, and concentration of simulated pollutants. The yearly summary in Table 33 contains analogous values for the entire year, in addition to the average, standard deviation, maximum, minimum, and range of values for storm events for the following information:

total runoff
peak flow
total pollutant washoff
maximum pollutant mass washoff
mean pollutant concentration
maximum pollutant concentration

Although mean or average conditions have little meaning in the evaluation of nonpoint pollution, these values are provided by the NPS Model in order to supply the information in a form useful to the user. Obviously, many users of the NPS Model may be forced by financial or time considerations to employ analysis techniques requiring only mean daily, monthly, or yearly pollutant loadings on a per acre or per stream-mile basis. In such situations, the necessary information can be obtained directly from the NPS Model output. However, for users requiring complete definition of the hydrograph and pollutant graph, the standard output for each storm event is provided. The NPS Model also includes the option (HYCAL=4) to write output to a separate file, or output device, for later input to a continuous or event stream simulation model. The output is essentially identical to production run output (Table 29) except that headings, titles and all summaries are excluded. A row of dashes (--) separate the information for different storm events. The format for the output is shown in Table 34. The intent of this option is to allow users to simulate larger watersheds if a suitable stream simulation model is available to accept the land surface simulation output from the NPS Model. In addition, statistical analysis of the output could provide probabilities of nonpoint pollution for use in the evaluation of alternate management policies.

Table 30. DAILY SNOWMELT OUTPUT
(Calibration run, English units)

SNOWMELT OUTPUT FOR DECEMBER 1

HOUR	PACK	DEPTH	SDEN	ALBEDO	CLDF	NEGMELT	LIQW	TX	RA	LW	PX	MELT	CONV	RAINM	CONDS	ICE
1	0.6	3.0	0.204	0.735	1.000	0.013	0.018	23.77	0.	-8.	0.0	0.0	0.0	0.0	0.0	0.4
2	0.6	3.0	0.204	0.734	1.000	0.017	0.018	22.61	0.	-8.	0.0	0.0	0.0	0.0	0.0	0.4
3	0.6	3.0	0.204	0.733	1.000	0.021	0.018	21.74	0.	-8.	0.0	0.0	0.0	0.0	0.0	0.4
4	0.6	3.0	0.205	0.732	1.000	0.023	0.018	21.16	0.	-8.	0.0	0.0	0.0	0.0	0.0	0.4
5	0.6	3.0	0.205	0.731	1.000	0.024	0.018	20.58	0.	-9.	0.0	0.0	0.0	0.0	0.0	0.4
6	0.6	3.0	0.205	0.730	1.000	0.025	0.018	20.00	0.	-9.	0.0	0.0	0.0	0.0	0.0	0.4
7	0.6	3.0	0.204	0.730	1.000	0.024	0.018	20.38	1.	-9.	0.0	0.0	0.0	0.0	0.0	0.4
8	0.6	3.0	0.204	0.729	1.000	0.022	0.018	21.52	2.	-8.	0.0	0.0	0.0	0.0	0.0	0.4
9	0.6	3.0	0.204	0.728	1.000	0.016	0.018	24.18	3.	-8.	0.0	0.0	0.0	0.0	0.0	0.4
10	0.6	3.0	0.204	0.727	1.000	0.009	0.018	27.60	4.	-7.	0.0	0.0	0.0	0.0	0.0	0.4
11	0.6	3.0	0.203	0.726	1.000	0.001	0.018	31.40	5.	-7.	0.0	0.0	0.0	0.0	0.0	0.4
12	0.6	3.0	0.202	0.725	1.000	0.001	0.018	34.63	5.	-6.	0.0	0.0	0.002	0.0	0.0	0.4
13	0.6	2.9	0.203	0.725	1.000	0.0	0.018	37.10	5.	-6.	0.0	0.003	0.005	0.0	0.0	0.4
14	0.6	2.9	0.204	0.724	1.000	0.0	0.018	38.24	5.	-5.	0.0	0.006	0.006	0.0	0.0	0.4
15	0.6	2.9	0.205	0.723	1.000	0.0	0.017	38.81	5.	-5.	0.0	0.007	0.007	0.0	0.0	0.4
16	0.6	2.9	0.206	0.722	1.000	0.0	0.017	39.00	5.	-5.	0.0	0.005	0.007	0.0	0.0	0.4
17	0.6	2.8	0.205	0.721	1.000	0.0	0.017	38.05	4.	-5.	0.0	0.002	0.006	0.0	0.0	0.4
18	0.6	2.8	0.204	0.721	1.000	0.0	0.017	36.72	3.	-6.	0.0	0.0	0.004	0.0	0.0	0.4
19	0.6	2.8	0.204	0.720	1.000	0.0	0.017	34.82	1.	-6.	0.0	0.0	0.002	0.0	0.0	0.4
20	0.6	2.8	0.203	0.719	1.000	0.0	0.017	32.35	0.	-7.	0.0	0.0	0.000	0.0	0.0	0.4
21	0.6	2.8	0.203	0.718	1.000	0.002	0.017	29.50	0.	-7.	0.0	0.0	0.0	0.0	0.0	0.4
22	0.6	2.8	0.202	0.717	1.000	0.005	0.017	27.03	0.	-7.	0.0	0.0	0.0	0.0	0.0	0.4
23	0.6	2.8	0.202	0.717	1.000	0.009	0.017	24.75	0.	-8.	0.0	0.0	0.0	0.0	0.0	0.4
24	0.6	2.8	0.202	0.716	1.000	0.014	0.017	23.23	0.	-8.	0.0	0.0	0.0	0.0	0.0	0.4

Table 31. DAILY SNOWMELT OUTPUT DEFINITIONS
(Calibration run, English units)

HOUR:	Hour of the day, numbered 1 to 24
PACK:	Water equivalent of the snowpack, inches
DEPTH:	Snow depth, inches
SDEN:	Snow density in inches of water per inch of snow
ALBEDO:	Albedo, or snow reflectivity, percent
CLDF:	Fraction of sky that is cloudless
NEGMELT:	Heat loss from the snowpack, equivalent inches of melt
LIQW:	Liquid water content of the snowpack, inches
TX:	Hourly air temperature, degrees Fahrenheit
RA:	Incident solar radiation, langleys
LW:	Net terrestrial radiation, langleys (negative value indicates outgoing radiation from the pack)
PX:	Total snowmelt reaching the land surface, inches
MELT:	Total melt, inches
CONV:	Convection melt, inches
RAINM:	Rain melt, inches
CONDS:	Condensation melt, inches
ICE:	Ice formation at the land surface, inches

Table 32. MONTHLY SUMMARY OUTPUT OF THE NPS MODEL

SUMMARY FOR MONTH OF JANUARY 1972

	TOTAL			
WATER, IN				
RUNOFF				
OVERLAND FLOW	0.014			
INTERFLOW	0.303			
IMPERVIOUS	0.590			
BASE FLOW	0.449			
TOTAL	1.356			
GRDWATER RECHARGE	0.0			
PRECIPITATION	2.576			
EVAPOTRANSPIRATION				
POTENIAL	1.180			
NET	0.997			
STORAGES				
UPPER ZONE	0.553			
LOWER ZONE	7.033			
GROUNDWATER	1.403			
INTERCEPTION	0.0			
OVERLAND FLOW	0.0			
INTERFLOW	0.0			
WATER BALANCE	0.0			
SEDIMENTS ACCUMULATION ,TONS/ACRE		WEIGHTED MEAN	PERVIOUS	IMPERVIOUS
OPEN AREA		0.351	0.364	0.104
RESID.AREA		0.660	0.729	0.347
COMMERCIAL		0.574	0.814	0.378
INDUSTRIAL		0.523	0.864	0.410
WEIGHTED MEAN		0.597	0.695	0.373
SEDIMENTS LOSS,	TOTAL (TONS)	TOTAL (LB /ACRE)	PERVIOUS (%)	IMPERVIOUS (%)
OPEN AREA	1.091	20.418	5.546	94.454
RESID.AREA	22.746	70.933	1.378	98.622
COMMERCIAL	19.472	214.296	0.250	99.750
INDUSTRIAL	20.275	291.788	0.102	99.898
TOTAL LOSS	63.587	118.965	0.697	99.303
POLLUTANT WASHOFF,	TOTAL (LB)	TOTAL (LB /ACRE)	PERVIOUS (%)	IMPERVIOUS (%)
WASHOFF OF BOD				
OPEN AREA	87.307	0.817	5.546	94.454
RESID.AREA	1819.914	2.837	1.378	98.622
COMMERCIAL	1557.759	8.572	0.250	99.750
INDUSTRIAL	1621.995	11.672	0.102	99.898
TOTAL WASHOFF	5086.975	4.759	0.697	99.303
WASHOFF OF SS				
OPEN AREA	1549.709	14.497	5.546	94.454
RESID.AREA	32303.512	50.364	1.378	98.622
COMMERCIAL	27650.270	152.150	0.250	99.750
INDUSTRIAL	28790.434	207.170	0.102	99.898
TOTAL WASHOFF	90293.875	84.466	0.697	99.303
STORM WATER QUALITY - AVERAGES				
TEMPERATURE (F)	48.45			
DISSOLVED OXYGEN (PPM)	11.657			
SEDIMENTS (GM/L)	0.093			
BOD (GM/L)	0.004			
SS (GM/L)	0.066			
NO. OF STORMS	11			

Table 33. ANNUAL SUMMARY OUTPUT OF THE NPS MODEL

SUMMARY FOR 1972

	TOTAL
WATER, IN	
RUNOFF	
OVERLAND FLOW	6.981
INTERFLOW	8.509
IMPERVIOUS	16.055
BASE FLOW	5.631
TOTAL	37.144
GROWATER RECHARGE	0.0
PRECIPITATION	64.688
EVAPOTRANSPIRATION	
POTENIAL	39.993
NET	25.150
STORAGES	
UPPER ZONE	0.953
LOWER ZONE	7.945
GROUNDWATER	2.447
INTERCEPTION	0.084
OVERLAND FLOW	0.0
INTERFLOW	0.056
WATER BALANCE	0.0

SEDIMENTS LOSS,	TOTAL (TONS)	TOTAL (TONS/ACRE)	PERVIOUS (%)	IMPERVIOUS (%)
OPEN AREA	239.148	2.237	93.919	6.081
RESID.AREA	1809.324	2.821	64.291	35.709
COMMERCIAL	772.302	4.250	23.419	76.581
INDUSTRIAL	725.830	5.223	10.586	89.414
TOTAL LOSS	3546.604	3.318	46.398	53.602

POLLUTANT WASHOFF,	TOTAL (LB)	TOTAL (LB /ACRE)	PERVIOUS (%)	IMPERVIOUS (%)
WASHOFF OF BOD				
OPEN AREA	19131.941	178.971	93.919	6.081
RESID.AREA	144744.875	225.670	64.291	35.709
COMMERCIAL	61783.578	339.975	23.420	76.580
INDUSTRIAL	58065.547	417.828	10.587	89.413
TOTAL WASHOFF	283725.875	265.412	46.398	53.602
WASHOFF OF SS				
OPEN AREA	339592.000	3176.727	93.919	6.081
RESID.AREA	2569219.000	4005.643	64.291	35.709
COMMERCIAL	1096658.000	6034.547	23.420	76.580
INDUSTRIAL	1030661.250	7416.430	10.587	89.413
TOTAL WASHOFF	5036129.000	4711.063	46.398	53.602

STORM WATER QUALITY - AVERAGES	
TEMPERATURE (F)	56.28
DISSOLVED OXYGEN (PPM)	10.742
SEDIMENTS (GM/L)	0.103
BOD (GM/L)	0.004
SS (GM/L)	0.073
NO. OF STORMS	115

SUMMARY OF STORMS' CHARACTERISTICS	AVERAGE	ST.DEV.	MAXIMA	MINIMA	RANGE
SEDIMENTS LOSS					
TOTAL WASHOFF (TONS)	30.530	57.332	298.848	0.000	298.848
MAX WASHOFF (LB /15MIN)	18831.363	47604.699	411374.438	0.000	411374.438
MEAN CONCENTRATION (GM/L)	0.641	0.445	1.823	0.000	1.823
MAX CONCENTRATION (GM/L)	1.267	0.995	3.917	0.000	3.917
WASHOFF OF BOD					
TOTAL WASHOFF (TONS)	1.221	2.293	11.954	0.000	11.954
MAX WASHOFF (LB /15MIN)	753.254	1904.178	16454.969	0.000	16454.969
MEAN CONCENTRATION (GM/L)	0.026	0.018	0.073	0.000	0.073
MAX CONCENTRATION (GM/L)	0.051	0.040	0.157	0.000	0.157
WASHOFF OF SS					
TOTAL WASHOFF (TONS)	21.676	40.706	212.183	0.000	212.183
MAX WASHOFF (LB /15MIN)	13370.250	33799.184	292075.750	0.000	292075.750
MEAN CONCENTRATION (GM/L)	0.455	0.316	1.294	0.000	1.294
MAX CONCENTRATION (GM/L)	0.899	0.707	2.781	0.000	2.781

Table 34. SAMPLE OUTPUT AND FORMAT FOR PRODUCTION RUN OUTPUT DIRECTED TO UNIT 4 (HYCAL=4)

								For Each Pollutant Simulated (maximum of 5)			
Data type	Year	Date	Time	Flow	Temp	DO	Sediment		Pollutant #1		Pollutant #2
Format	I4	A4 1X I2	1X I2 1A I2	F8.3	F5.2	F5.2	F9.2	F8.3	F8.2	F8.3	F8.2	F8.3
English units				cfs	°F	ppm	lb	gm/l	lb	gm/l	lb	gm/l
Metric units				m^3	°C	ppm	kg	gm/l	kg	gm/l	kg	gm/l

Sample Output

```
1972 JAN 11 11: 0  25.54154.8010.58  1300.07   0.907   52.00   0.036  923.05   0.644
1972 JAN 11 11:15  32.50656.1610.40  1578.87   0.865   63.15   0.035 1121.00   0.614
1972 JAN 11 11:30  25.19056.1610.40  1126.56   0.797   45.06   0.032  799.85   0.566
1972 JAN 11 11:45  19.28156.1610.40   646.56   0.597   25.86   0.024  459.06   0.424
1972 JAN 11 12: 0  12.90856.1610.40   310.10   0.428   12.40   0.017  220.17   0.304
1972 JAN 11 21:45  10.04848.5511.50   189.11   0.335    7.56   0.013  134.27   0.238
1972 JAN 11 22: 0  10.69248.5511.50   254.09   0.423   10.16   0.017  180.41   0.301
1972 JAN 11 22:15  11.21746.7511.78   235.29   0.374    9.41   0.015  167.06   0.265
1972 JAN 11 23: 0  10.51746.7511.78   205.19   0.348    8.21   0.014  145.68   0.247
1972 JAN 11 23:45  10.29945.5511.98   195.39   0.338    7.82   0.014  138.73   0.240
1972 JAN 11 24: 0  10.89745.5511.98   259.27   0.424   10.37   0.017  184.08   0.301
1972 JAN 12  0:15  11.38644.9512.09   238.64   0.373    9.55   0.015  169.43   0.265
1972 JAN 13  4:30  12.34345.2212.04   575.07   0.830   23.00   0.033  408.30   0.589
1972 JAN 13  4:45  44.32345.2212.04  2171.29   0.873   86.85   0.035 1541.62   0.620
1972 JAN 13  5: 0  24.01245.2212.04  1091.90   0.810   43.68   0.032  775.25   0.575
1972 JAN 13  5:15  18.37345.0012.08   633.72   0.614   25.35   0.025  449.94   0.436
1972 JAN 13  5:30  12.12145.0012.08   305.36   0.449   12.21   0.018  216.80   0.319
```

Note: The format for reading output data from unit 4 is FORMAT (I4, A4, 2(1X,I2), 1A, I2, F8.3, 2(F5.2), F9.2, F8.3, 5(F8.2, F8.3)).

A5. MODEL PARAMETERS AND PARAMETER EVALUATION

The NPS Model includes parameters that must be evaluated whenever the Model is applied to a specific watershed. Since the Model is designed to be applicable to watersheds across the county, the parameters provide the mechanism to adjust the simulation for the specific topographic, hydrologic, edaphic, and land use conditions of the watershed. The large majority of the parameters are easily evaluated from known watershed characteristics. Parameters that cannot be precisely determined in this manner must be evaluated through calibration with recorded data. This section discusses and defines the NPS Model parameters, the parameter input sequence, and methods of parameter evaluation. Section A6 provides calibration procedures and guidelines.

Table 35 lists and briefly defines the NPS Model parameters while Table 36 describes the parameter input sequence and attributes (units, type, and options, etc.). The major parameters will be further discussed with methods of evaluation. Parameter input is accomplished in the FORTRAN 'namelist' format except for alphanumeric variables which are input under a fixed format. The parameters are divided into the categories of simulation control, hydrology, snow, and water quality. As indicated in Table 36, the control parameters begin the parameter input sequence. The first two lines provide space for the watershed name and identification of the specific simulation run. This information is followed by the control namelists (ROPT, DTYP, STRT, ENDD) that include parameters specifying units, run options, and the beginning and ending dates of the simulation period. The hydrology namelists (LND1, LND2, LND3, LND4) are next in sequence. If snow simulation is to be performed, the snow namelists (SNO1, SNO2, SNO3, SNO4, SNO5) follow; otherwise the water quality parameters and namelists begin. As indicated in Table 36, the water quality information begins with the specification of the washoff 'namelist' (WASH) followed by the names of the nonpoint pollutants to be simulated (one name per line). Each pollutant name is followed (column #15) by the concentration units to be used. Either gm/l or mg/l can be specified, and gm/l is the default specification.

Next, a block of information for each land use follows the pollutant names and units. This block of information contains the land use name followed by the water quality namelists (WSCH, MPTM or YPTM, MACR or YACR, MRMR or YRMR, INAC) with the parameter values for the specific land use. These parameters specify land cover, impervious area, land use area, potency factors, accumulation, and removal rates; all these parameters are specific to each land use. (Note that different input namelist names are used to indicate average annual and monthly variations for potency factors, sediment accumulation, and sediment

Table 35. NPS MODEL INPUT PARAMETER DESCRIPTION

Type	Name	Description
Control	HYCAL	Type of simulation run desired: (1) hydrologic calibration (HYCAL=1) (2) sediments and quality calibration (HYCAL=2) (3) production run--printer output only (HYCAL=3) (4) production run--printer and unit 4 output (HYCAL=4)
	HYMIN	Minimum flow for output during a time interval
	NLAND	Number of land type uses within watershed (up to five)
	NQUAL	Number of optional quality constituents simulated (up to 5)
	SNOW	Controls snowmelt simulation: (1) snowmelt performed (SNOW=1) (2) snowmelt not performed (SNOW=0)
	UNIT	Specifies units of input and output: (1) English units (UNIT=-1) (2) metric units (UNIT=1)
	PINT	Specifies type of input precipitation data: (1) 15 minute intervals (PINT=0) (2) hourly intervals (PINT=1)
	MNVAR	Specifies type of input quality data (1) mean monthly accumulation and removal data (MNVAR=1) (2) mean annual accumulation and removal rates (MNVAR=0)
	BGNDAY BGNMON BGNYR	Date simulation begins: day, month, year
	ENDDAY ENDMON ENDYR	Date simulation ends: day, month, year
Hydrology	UZSN	Nominal upper zone storage
	LZSN	Nominal lower zone storage
	INFIL	Mean infiltration rate
	INTER	Interflow parameter, alters runoff timing
	IRC	Interflow recession rate
	AREA	Watershed area
	NN	Manning's "n" for overland flow on pervious areas
	SS	Average slope of overland flow on pervious areas
	L	Length of overland pervious flow to channel
	NNI	Manning's "n" for overland flow on impervious areas
	SSI	Average slope of overland flow on impervious areas
	LI	Length of overland impervious flow to channel
	K1	Ratio of spatial average rainfall to gage rainfall
	PETMUL	Potential evapotranspiration data correction factor

Table 35 (continued). NPS MODEL INPUT PARAMETER DESCRIPTION

Type	Name	Description
	K3	Index to actual evapotranspiration
	EXPM	Maximum interception storage
	K24L	Fraction of groundwater recharge percolating to deep groundwater
	KK24	Ground recession rate
	UZS	Initial upper zone storage
	LZS	Initial lower zone storage
	SGW	Initial groundwater storage
Snow	RADCON	Correction factor for radiation melt
	CCFAC	Correction factor for condensation and convection melt
	EVAPSN	Correction factor for snow evaporation
	MELEV	Mean elevation of watershed
	ELDIF	Elevation difference from temperature station to mean watershed elevation
	TSNOW	Temperature below which precipitation occurs as snow
	MPACK	Water equivalent of snowpack for complete watershed coverage
	DGM	Daily groundmelt
	WC	Water content of snowpack by height
	IDNS	Initial density of new snow
	SCF	Snow correction factor for raingage catch deficiency
	WMUL	Wind data correction factor
	RMUL	Radiation data correction factor
	F	Fraction of watershed with complete forest cover
	KUGI	Index to forest density and undergrowth
	PACK	Initial water equivalent of snowpack
	DEPTH	Initial depth of snowpack
Quality	JRER	Exponent of rainfall intensity in soil splash equation
	KRER	Coefficient in soil splash equation
	JSER	Exponent of overland flow in sediment washoff equation from pervious areas
	KSER	Coefficient in sediment washoff equation from pervious areas
	JEIM	Exponent of overland flow in sediment washoff equation for impervious areas
	KEIM	Coefficient in sediment washoff equation for impervious areas
	TCF	Monthly water temperature correction factors

The following parameters are required for each land use simulated:

ARFRAC	Fraction of the total watershed area with this land use
IMPKO	Impervious fraction of the land use area

Table 35 (continued). NPS MODEL INPUT PARAMETER DESCRIPTION

Type	Name	Description
	COVVEC	Mean monthly land cover factors for pervious areas
	PMPVEC	Mean annual potency factors for pervious areas
	PMIVEC	Mean annual potency factors for impervious areas
	PMPMAT	Mean monthly potency factors for pervious areas (optional)
	PMIMAT	Mean monthly potency factors for impervious areas (optional)
	ACUP	Daily accumulation rates of deposits on pervious areas mean annual values
	ACUI	Daily accumulation rates of deposits on impervious areas mean annual values
	ACUPV	Daily accumulation rates of deposits on pervious areas mean monthly values (optional)
	ACUIV	Daily accumulation rates of deposits on impervious areas mean monthly values (optimal)
	REPER	Daily removal rates of sediments from pervious areas mean annual values
	REIMP	Daily removal rates of sediments from impervious areas mean annual values
	REPERV	Daily removal rates of sediments from pervious areas mean monthly values (optional)
	REIMPV	Daily removal rates of sediments from impervious areas mean monthly values (optional)
	SRERI	Initial accumulation of sediments on pervious areas
	TSI	Initial accumulation of sediments on impervious areas

Table 36. NPS MODEL PARAMETER INPUT SEQUENCE AND ATTRIBUTES

Namelist Name	Parameter Name	Type	English Units	Metric Units	Comment
	Watershed Name	character			up to 8 characters
	Computer Run Information	character			up to 8 characters
ROPT	HYCAL	integer			
	HYMIN	real	ft^3/sec	m^3/sec	1, 2, 3, or 4
	NLAND	integer			up to 5 land uses
	NQUAL	integer			up to 5 pollutants
	SNOW	integer			0 or 1
DTYP	UNIT	integer			0 or 1
	PINT	integer			0 or 1
	MNVAR	integer			0 or 1
STRT	BGNDAY	integer			
	BGNMON	integer			
	BGNYR	integer			
ENDD	ENDDAY	integer			
	ENDMON	integer			
	ENDYR	integer			
LND1	UZSN	real	inches	millimeters	
	LZSN	real	inches	millimeters	
	INFIL	real	in/hr	mm/hr	
	INTER	real			
	IRC	real			
	AREA	real	acres	hectares	
LND2	NN	real			
	L	real	feet	meters	
	SS	real			
	NNI	real			
	LI	real	feet	meters	
	SSI	real			
LND3	K1	real			
	PETMUL	real			
	K3	real			
	EXPM	real	inches	millimeters	
	K24L	real			
	KK24	real			

Table 36 (continued). NPS MODEL PARAMETER INPUT SEQUENCE AND ATTRIBUTES

Namelist Name	Parameter Name	Type	English Units	Metric Units	Comment
LND4	UZS	real	inches	millimeters	
	LZS	real	inches	millimeters	
	SGW	real	inches	millimeters	
SNO1	RADCON	real			
	CCFAC	real			
	EVAPSN	real			
SNO2	MELEV	real	feet	meters	
	ELDIF	real	1000 feet	kilometers	
	TSNOW	real	degrees F	degrees C	
SNO3	MPACK	real	inches	millimeters	
	DGM	real	in/day	mm/day	
	WC	real			
	IDNS	real			
SNO4	SCF	real			
	WMUL	real			
	RMUL	real			
	F	real			
	KUGI	integer			
SNO5	PACK	real	inches	millimeters	
	DEPTH	real	inches	millimeters	
WASH	JRER	real			
	KRER	real			
	JSER	real			
	KSER	real			
	JEIM	real			
	KEIM	real			
	TCF	real			12 values
	Pollutant name	character			up to 8 characters[a] repeat for each pollutant
REPEAT THE FOLLOWING INFORMATION FOR EACH LAND USE					
	Land Use Type	character			up to 12 characters
WSCH	ARFRAC	real			
	IMPKO	real			
	COVVEC	real			12 values

a. Each pollutant name is followed by the concentration units to be used, either 'MG/L' or 'GM/L,' beginning in column no. 15 (see Appendix D). 'GM/L' is the default value.

Table 36 (continued). NPS MODEL PARAMETER INPUT SEQUENCE AND ATTRIBUTES

Namelist Name	Parameter Name	Type	English Units	Metric Units	Comment
YPTM	PMPVEC PMIVEC	real real	percent percent	percent percent	1 value per pollutant include if MNVAR=0
MPTM	PMPMAT PMIMAT	real real	percent percent	percent percent	12 values per pollutant include if MNVAR=1
YACR	ACUP ACUI	real real	lb/ac/day lb/ac/day	km/ha/day km/ha/day	1 value per pollutant include if MNVAR=0
MACR	ACUPV ACUPI	real real	lb/ac/day lb/ac/day	km/ha/day km/ha/day	12 values per pollutant include is MNVAR=1
YRMR	REPER REIMP	real real	day^{-1} day^{-1}	day^{-1} day^{-1}	1 value per pollutant include if MNVAR=0
MRMR	REPERV REIMPV	real real	day^{-1} day^{-1}	day^{-1} day^{-1}	12 values per pollutant include if MNVAR=1
INAC	SRERI TSI	real real	lb/ac lb/ac	kg/ha kg/ha	

removal rates.) The block of land use information is repeated for each land use in the watershed. The last land use information completes the parameter input sequence. Reference to Table 36 and the sample input listing in Appendix D should clarify the parameter input sequence of the NPS Model.

Parameter Evaluation

Guidelines for evaluating the NPS Model parameters relating to hydrology, snowmelt, and nonpoint pollutant simulation are provided below. The simulation control parameters are self-explanatory by their definitions in Table 35 and are not discussed. Also, guidelines are provided below for obtaining initial values of the calibration parameters. However, precise evaluation of these parameters can only be obtained through calibration as discussed in Section A6.

Hydrology Parameters-

HYMIN: Although HYMIN is a control parameter representing the minimum flow above which storm output is printed, it also has a direct impact on the storm summary characteristics printed at the end of each storm. A storm is defined to begin when the flow exceeds HYMIN, and ends when the flow falls below HYMIN. The storm summary characteristics pertain to the intervening period. Thus HYMIN should be chosen to include the significant portion of the hydrograph and pollutant graph within the defined storm period. Investigation of recorded storm hydrographs and pollutant graphs will indicate an appropriate value for HYMIN.

EPXM: This interception storage parameter is a function of cover density. The following values are expected:

urban areas with average imperviousness	0.05 in.
grassland	0.10 in.
forest cover (light)	0.15 in.
forest cover (heavy)	0.20 in.

Since EPXM applies to the entire watershed, areas with much imperviousness may require values in the lower end of the above range, e.g., 0.01-0.05 in.

UZSN: The nominal storage in the upper zone is generally related to LZSN and watershed topography. However, agriculturally managed watersheds may deviate significantly from the following guidelines:

Low depression storage, steep slopes, limited vegetation	0.06*LZSN
Moderate depression storage slopes and vegetation	0.08*LZSN
High depression storage, soil fissures, flat slopes, heavy vegetation	0.14*LZSN

LZSN: The nominal lower zone soil moisture storage parameter is related to the annual cycle of rainfall and evapotranspiration. Approximate values range from 5.0 to 20.0 inches for most of the continental United States depending on soil properties. Figure 33 presents an approximate mapping of LZSN values for the United States. This map was obtained by overlaying climatic, topographic, physiographic, and soils information with LZSN values for watersheds calibrated with various versions of the Stanford Watershed Model hydrologic algorithms. The watershed locations are shown in Figure 34 and listed in Table 37 with various watershed characteristics and calibrated parameter values. Since Figure 34 shows that many areas of the country have few calibrated watersheds, Figure 37 and Table 37 should be used with caution. Initial values of LZSN can be obtained from this information, but the proper value will need to be checked by calibration.

K3: As an index to actual evapotranspiration, K3 affects evapotranspiration from the lower soil moisture zone. The area covered by forest or deep rooted vegetation as a fraction of total watershed area is an estimate of K3. Values generally range from 0.25 for open land and grassland to 0.7-0.9 for heavy forest.

K24L: This parameter controls the loss of water from the near surface or active ground water storage to deep percolation. K24L is the fraction of the ground water recharge that percolates to the deep ground water table. Thus a value of 1.0 for K24L would preclude any ground water contribution to streamflow and is used on small watersheds without a base flow component from ground water.

INFIL: This parameter is an index to the mean infiltration rate on the watershed and is generally a function of soil characteristics. INFIL can range from 0.01 to 1.0 in./hr depending on the cohesiveness and permeability of the soil.

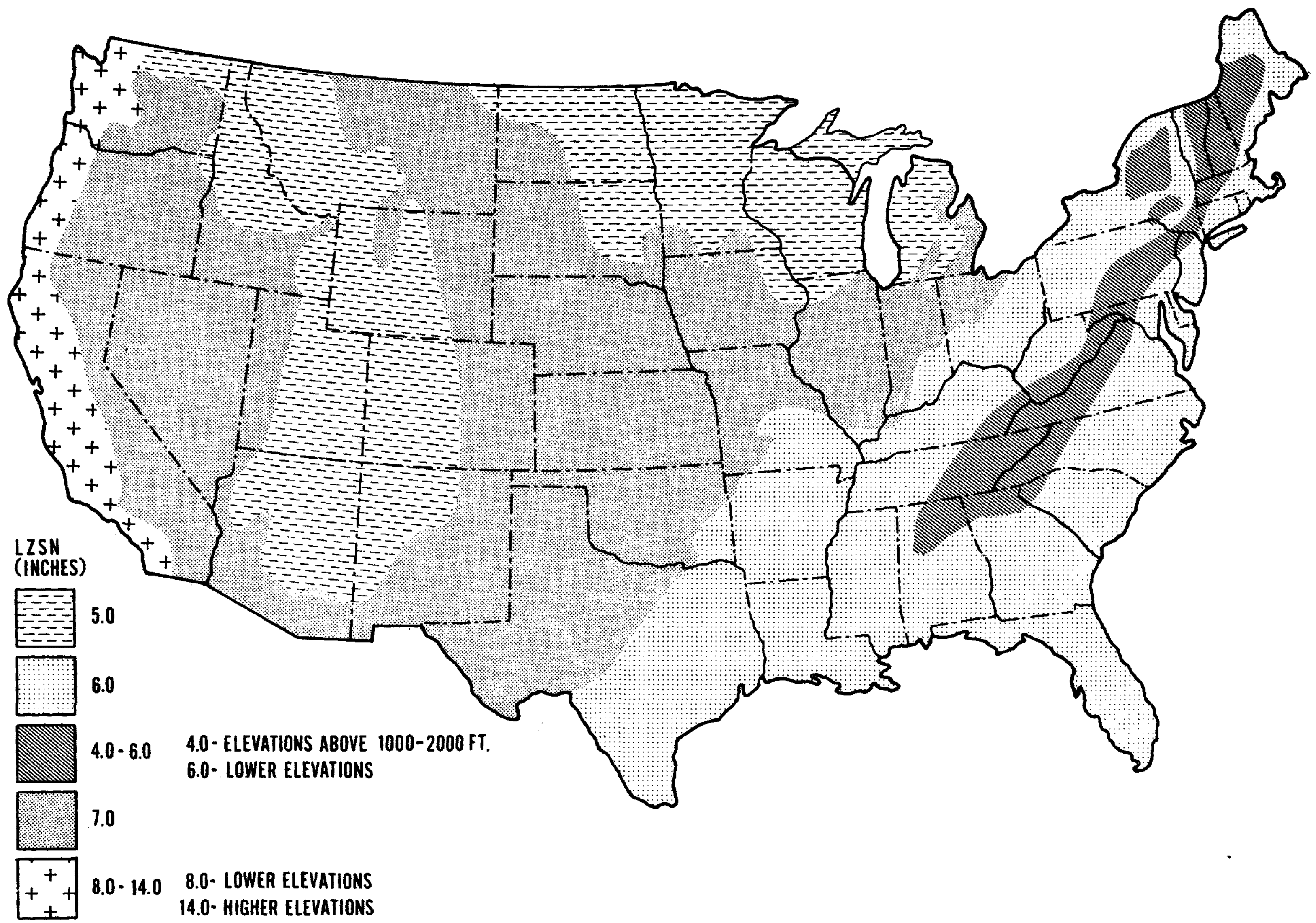

Figure 33. Nominal lower zone soil moisture (LZSN) parameter map

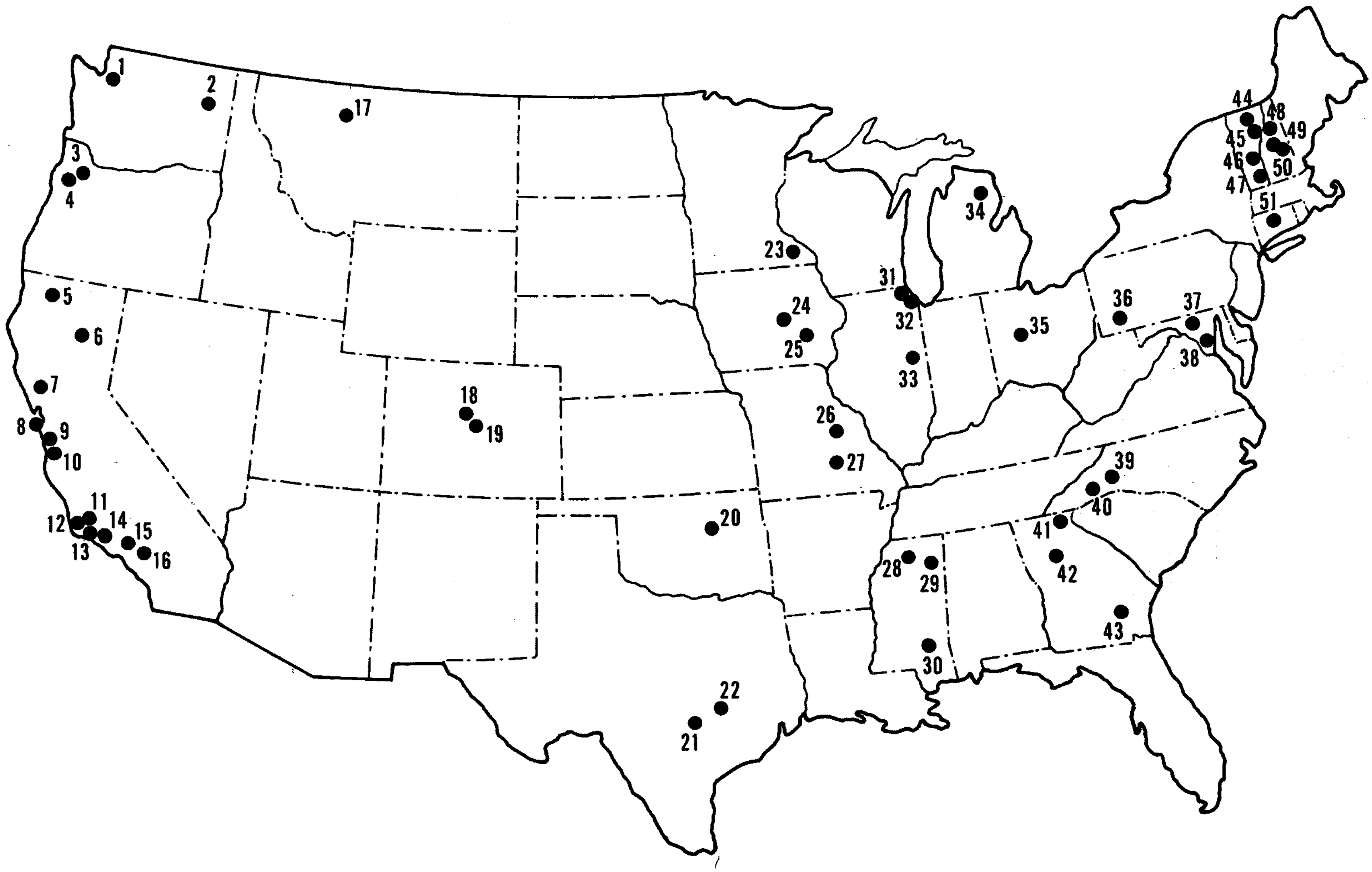

Figure 34. Watershed locations for calibrated LANDS parameters

Table 37. WATERSHEDS WITH CALIBRATED LANDS PARAMETERS

Watershed Information			Area (sq mi)	Type	LANDS Parameters					
No.	General Location	Name			Model[a]	UZSN	LZSN	INFIL	INTER	Comments[b]
1	Seattle, Washington	Lower Green R			HSP	3.0	12.0	0.06	10.0	
		Middle Green R			HSP	1.15	9.5	0.10	3.0	
		Upper Green R			HSP	0.9	14.0	0.05	11.5	
		Lake Washington			HSP	0.5	8.0	0.05	10.0	
2	Spokane, WA	Little Spokane R		plains, rural	HSP	0.56	7.0	0.20	15	
3	Aschoft, Oregon	Bull Run	107	rural, steep forest	HSP	0.75	14.0	0.08	3.5	
4	Whiteson, Oregon	South Yamhill R	502		NWS	1.20	5.3	0.24	0.5	POWER=0.37
5	Central Sierra Snowlab, CA	Upper Castle Creek	3.96	rural, rocky forest	NWS	0.70	9.0	0.08	0.67	POWER=1.5
6	between Chico and Flemming, CA	N Fork Feather R	300	rural, steep forest	HSP	0.8	12.0	0.12	2.5	
7	Cloverdale, CA	Dry Creek	878	rural, moderate slope,chaparral	SWM V	0.8	15.0	0.03	1.8	
	Napa, CA	Dry Creek	14.4	rural, moderate slope, chaparral	HSP	0.8	12.0	0.025	2.5	
8	Burlingame, CA	Colma Creek	10.8	urban, moderate slopes	HSP	0.25	12.0	0.07	2.0	
9	Santa Cruz, CA	Branciforte Creek	17.3	rural	HSP	1.0	16.0	0.04	2.5	
10	San Mateo Co, CA	Denniston Creek	3.6	rural, steep chaparral	SWM IV	0.95	12.7	1.35	2.0	
11	Santa Ynez, CA	Sisquoc River	281	rural, steep light chaparral	HSP	0.7	8.5	0.18	1.5	
12	Santa Maria, CA	Santa Maria River	2.38	urban, flat slopes	HSP	0.3	5.0	0.02	1.4	
13	Goleta, CA	San Jose Creek	5.5	rural, steep	HSP	0.5	10.0	0.03	3.5	
14	Santa Ynez, CA	Santa Ynez River	895	rural, steep	HSP	0.74	8.3	0.035	1.5	
15	Los Angeles, CA	Echo Park	0.4	urban, steep residential	HSP	0.04	5.0	0.03	0	
16	Pasadena, CA	Arroyo Seco	16	urban, steep	HSP	0.20	7.0	0.05	1.2	
17	Upper Columbia Snowlab, MT	Skyland Creek	8.1	rural, steep	NWS	1.83	10.7	0.071	5.6	POWER=0.83
18	Denver, CO	South Platte R		rural, moderate slope, grasses	HSP	0.1	0.7	0.03	1.0	
19	30 mi. south of Denver, CO	Cherry Creek	69	rural, moderate	HSP	0.8	7.0	0.005	3.0	

Table 37 (continued). WATERSHEDS WITH CALIBRATED LANDS PARAMETERS

Watershed Information					LANDS Parameters					
No.	General Location	Name	Area (sq mi)	Type	Model[a]	UZSN	LZSN	INFIL	INTER	Comments[b]
				slope, grassland						
20	Sperry, OK	Bird Creek	905		NWS	1.38	10.0	0.048	0.67	POWER=0.78
21	Austin, TX	Waller Creek	6.5	urban, moderate	HSP	1.0	8.0	0.04	1.25	
22	Bryon, TX	Burton Creek	1.3	urban, flat	HSP	0.3	5.0	0.02	1.5	
23	Lannesboro, MN	Root River	625		NWS	0.2	5.0	0.08	0.5	POWER=2.0
24	Rock Rapids, IA	Rock River	788		NWS	0.75	4.0	0.02	1.4	POWER=2.5
25	Iowa City, IA	Rapid Creek	25.3		HSP	0.5	7.0	0.035	3.5	
26	St. James, MO	Bourbeuse River	21.3		HSP	0.75	5.0	0.02	1.0	
27	Steelville, MO	Meramec River	781		NWS	1.2	12.7	0.043	1.05	POWER=1.56
28										
29	Nettleton, MO	Town Creek	617		NWS	0.44	7.35	0.066	0.89	POWER=2.6
30	Collins, MI	Leaf River	752		NWS	0.05	7.5	0.33	0.37	POWER=2.85
31	Chicago, IL	North Branch, Chicago River	100	urban, flat,	HSP	1.4	7.5	0.18	3.5	
32	Northbrook, IL	W Fork N Branch Chicago River	11.5	rural	HSP	1.40	7.5	0.18	3.0	
33	Champaign/Urbana, IL	Boneyard Creek	3.6	urban, flat slope	HSP	0.80	7.5	0.05	2.0	
34	Selkirk, MI	S Branch Shepards Creek	1.2		HSP	1.0	5.0	0.04	1.0	
35	Springfield, OH	Mad River	490		NWS	0.41	4.1	0.125	0.83	POWER=0.40
36	Green Lick Reservoir, PA	Green Lick Run	3.1		HSP	1.0	8.0	0.007	1.0	
37	Frederic, MD	Monocacy River	817		NWS	1.2	1.75	0.058	1.0	POWER=0.30
38	E of Washington D.C. in MD	W Branch of Patuxent River	30.2	rural, flat	HSP	1.2	7.0	0.02	2.0	
39	Rosman, NC	French Broad R	67.9	rural, limestone forest	NWS	0.01	5.38	0.8	0.25	POWER=0.36
40	Swannanoa, NC	Beetree Creek	5.5	rural	HSP	0.30	3.0	0.10	30	
41	Blairsville, GA	Nottely River	74.8	rural, forest mountains	NWS	0.02	3.4	0.45	2.5	POWER=2.0
42	Fayetteville, GA	Camp Creek	17.2	urban, hilly forests	NWS	0.5	5.0	0.16	0.75	POWER=2.0
43	Alma, GA	Hurricane Creek	150	rural, forested	NWS	0.2	2.0	0.13	2.6	POWER=2.0
44	Danville, VT	Sleepers River	3.2	rural	NWS	0.25	4.55	0.40	0.25	POWER=3.0
45	Passumpic, VT	Passumpsic River	436	rural	NWS	0.15	5.0	0.33	0.9	POWER=3.0

Table 37 (continued). WATERSHEDS WITH CALIBRATED LANDS PARAMETERS

Watershed Information					LANDS Parameters					
No.	General Location	Name	Area (sq mi)	Type	Model[a]	UZSN	LZSN	INFIL	INTER	Comments[b]
46	West Hartford, VT	White River	690	rural	NWS	0.25	5.0	0.15	1.3	POWER=0.95
47	Grafton, VT	Saxton River	72.2		SWM V	0.8	8.0	0.05	2.0	
48	Bath, NH	Ammonoosuc River	395	rural	NWS	0.3	5.0	0.12	0.65	POWER=1.50
50	Plymouth, NH	Pemigewasset River	622	rural	NWS	0.25	5.0	0.22	0.53	POWER=2.08
51	Knightsville Dam, MA	Sykes Brook	1.6		HSP	1.2	8.0	0.03	1.0	
others										
52	Fairbanks, AK	Chena River	1980		NWS	0.05	5.0	0.08	0.25	POWER=1.0
53	Seattle, WA	Issaquah Creek	55	rural, steep heavy forest	HSP	1.12	14.0	0.03	7.0	
54	Spokane, WA	Hangman Creek	54	agriculture	HSP	0.50	7.0	0.02	3.5	
55	Santa Cruz, CA	Neary's Lagoon	1.0	urban, steep	HSP	0.80	11.0	0.04	2.5	
56	Ingham, Co. MI	Deer Creek	16.3	rural, flat agriculture	HSP	1.5	5.0	0.05	2.0	
57	Athens, GA	Southern Piedmont	0.01	small plot watersheds	PTP	0.05	18.0	0.5	0.7	
				RANGES		0.01-3.0	1.75-18	.005-1.35	0-30	

a. HSP Hydrocomp Simulation Program
SWM IV Stanford Watershed Model IV
SWM V Stanford Watershed Model V
NWS National Weather Service Model
PTR Pesticide Transport and Runoff Model

b. HSP and the SWM Models use a value of 2.0 in the infiltration function (see Appendix B), while the NWS Model allows the user to specify this value with the POWER parameter. The values of POWER are indicated in the comments column.

Initial values for INFIL can be obtained by reference to the hydrologic soil groups of the Soil Conservation Service (73) in the following manner:

SCS Hydrologic Soil Group	INFIL Estimate (in./hr)	Runoff Potential
A	0.4-1.0	low
B	0.1-0.4	moderate
C	0.05-0.1	moderate-to-high
D	0.01-0.05	high

The SCS has specified the hydrologic soil group for various soil classifications across the country (73). As for LZSN, the values of INFIL obtained above should be used with caution and only as initial values to be checked by calibration.

INTER: This parameter refers to the interflow component of runoff and generally alters runoff timing. It is closely related to INFIL and LZSN and values generally range from 0.5 to 5.0. Figure 39 provides an approximate mapping of the INTER parameter for the United States. This map was obtained as described for the LZSN parameter. In addition, INTER values in Table 37 provide an indication of representative values. This information should be used only to obtain initial values that need to be checked by calibration.

L, LI: Length of overland flow for pervious and impervious areas is obtained from topographic maps and approximates the length to a stream channel. The value for pervious areas can be approximated by dividing the entire watershed area by twice the length of the drainage path or channel. Values for impervious areas can be obtained by estimating the average width of impervious areas surrounding the drainage path or channel.

NN, NNI: Manning's n for overland flow will vary considerably from published channel values because of the extremely small depths of overland flow. Approximate values are:

smooth, packed surface	0.05
normal roads and parking lots	0.10
disturbed land surfaces	0.15
turf	0.25
heavy turf and forest litter	0.35

SS, SSI: Average overland flow slope (pervious and impervious) is also obtained from topographic maps. The average slope can be

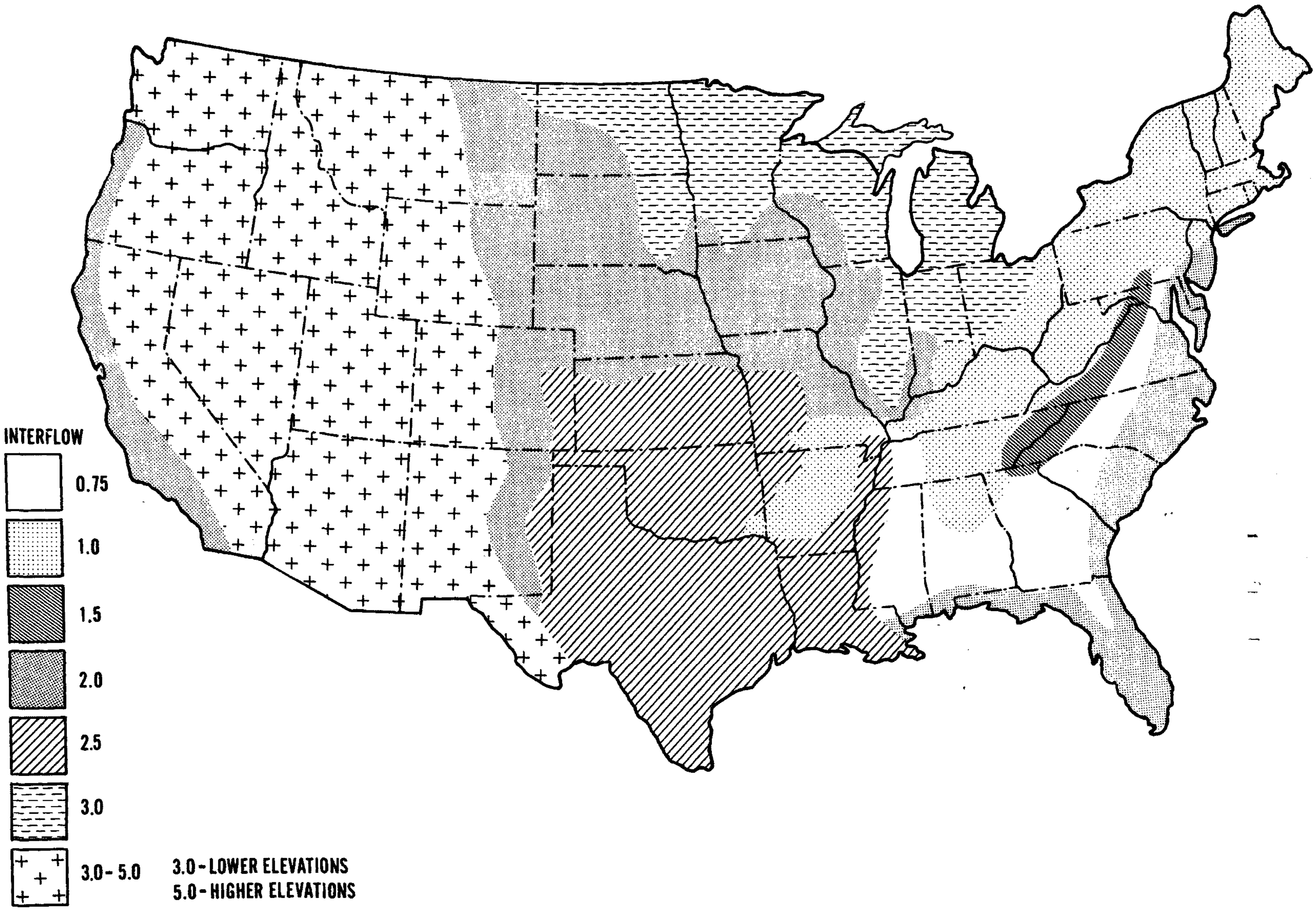

Figure 35. Interflow (INTER) parameter map

estimated by superimposing a grid pattern on the watershed, estimating the land slope at each point of the grid on pervious and impervious areas, and obtaining the average of all values measured in each category. Slopes of impervious areas will often be less than pervious slopes due to construction practices and specifications.

PETMUL: PETMUL adjusts the input potential evapotranspiration data to expected conditions on the watershed. Values near 1.0 are used if the input data has been collected on or near the watershed to be simulated.

IRC,
KK24: These parameters are the interflow and ground water recession rates. They can be estimated graphically by hydrograph separation techniques (74), or found by trial from simulation runs. Since these parameters are defined below on a daily basis, they are generally close to 0.0 for small watersheds that only experience runoff during or immediately following storm events.

$$IRC = \frac{\text{Interflow discharge on any day}}{\text{Interflow discharge 24 hours earlier}} \qquad (25)$$

$$KK24 = \frac{\text{Groundwater discharge on any day}}{\text{Groundwater discharge 24 hours earlier}} \qquad (26)$$

UZS, LZS
SGW: These parameters are the initial soil moisture conditions for the upper zone, lower zone, and ground water zone, respectively at the beginning of the simulation period. SGW is the component of ground water storage that contributes to streamflow. It is usually set to 0.0 for initial calibration runs. The factor (1.0-K24L) specifies the fraction of the total ground water component added to SGW, while the outflow from active ground water is determined by the recession rate, KK24 (see Appendix B). UZS and LZS are generally specified relative to their nominal storages, UZSN and LZSN. If simulation begins in a dry period, UZS and LZS should be less than their nominal values; whereas values greater than nominal should be employed if simulation begins in a wet period of the year. UZS, LZS, and SGW should be reset after a few calibration runs according to the guidelines provided in Section A6.

Snowmelt Parameters-

RADCON,
CCFAC: These parameters adjust the 'theoretical melt' equations for solar radiation and condensation/convection melt to actual field conditions. Values near 1.0 are to be expected, although past experience indicates a range of 0.5 to 2.0. RADCON is sensitive to watershed slopes and exposure, while CCFAC is a function of climatic conditions.

SCF: The snow correction factor is used to compensate for catch deficiency in rain gages when precipitation occurs as snow. Precipitation times (SCF-1.0) is the added catch. Values are generally greater than 1.0 and usually are in the range of 1.0 to 1.5.

ELDIF: This parameter is the elevation difference from the temperature station to the mean elevation in the watershed in thousands of feet (or kilometers). It is used to correct the observed air temperatures for the watershed using a lapse rate of 3 degrees F per 1,000 feet elevation change.

IDNS: This parameter is the density of new snow at 0 degrees F. The expected values are from 0.10 to 0.20 with 0.15 a common value. Appendix C provides a relationship for the variation in snow density with temperature.

F: This parameter is the fraction of the watershed that has complete forest cover. Areal photographs are the best basis for estimates.

DGM: DGM is the daily groundmelt. Values of 0.01 in/day or less are usual. Areas with deep frost penetration may have little groundmelt with DGM values approaching 0.0.

WC: This parameter is the maximum water content of the snowpack by weight. Experimental values range from 0.01 to 0.05 with 0.03 a common value.

MPACK: MPACK is the estimated water equivalent of the snowpack for complete areal coverage in a watershed. Values of 1.0 to 6.0 inches are generally employed. MPACK is a function of topography and climatic conditions. Mountainous watersheds will generally have MPACK values near the high end of the range.

EVAPSN: Adjusts the amounts of snow evaporation given by an analytic equation. Values near 0.1 are expected.

MELEV: The mean elevation of the watershed in feet (meters).

TSNOW: Temperature below which snow is assumed to occur. Values of 31 degrees to 33 degrees F are often used. Comparing the recorded form of precipitation and the simulated form for a number of years will indicate needed modifications to TSNOW.

WMUL, RMUL: These parameters are used to adjust input wind movement and solar radiation, respectively, for expected conditions on the watershed. Values of 1.0 are used if the input meteorologic data is observed on or near the watershed to be simulated.

KUGI: KUGI is an integer index to forest density and undergrowth for the reduction of wind in forested areas. Values range from 0 to 10; for KUGI = 0, wind in the forested area is 35 percent of the input wind value, and for KUGI = 10 the corresponding value is 5 percent. For medium undergrowth and forest density a value of 5 is generally used.

<u>Water Quality Parameters-</u>

JRER: JRER is the exponent in the soil splash equation (Equation 9) and thus approximates the relationship between rainfall intensity and incident energy to the land surface for the production of soil fines. Wischmeier and Smith (75) have proposed the following relationship for the kinetic energy produced by natural rainfall;

$$Y = 916 + 331 \log X \qquad (27)$$

where Y = kinetic energy, foot-tons per acre-in.
X = rainfall intensity, in./hr

Using this relationship, various investigations have also shown that soil splash is proportional to the square of the rainfall intensity (60, 76). Thus, a value of about 2.0 for JRER is predicted from these studies. In general, values in the range of 2.0 to 3.0 have demonstrated reasonable results on the limited number of watersheds tested. The best value will need to be checked through calibration.

KRER: This parameter is the coefficient of the soil splash equation and is related to the erodibility or detachability of the specific soil type. KRER is directly related to the 'K' factor in the Universal Soil Loss Equation (54). Initially

KRER can be set equal to the corresponding K factor for the watershed. K values can be obtained with techniques published in the literature (51, 77) or from soil scientists familiar with local soil conditions. Table 38 provides a sample list of estimated K values for various soils, and Figure 36 is a nomograph for general estimation of K from soil properties. Other available information on K factors for the specific watershed should be consulted. However, this initial value will need to be checked through calibration trials.

JSER,
JEIM: These parameters are the exponents in the sediment washoff, or transport, equations for pervious and impervious areas, and thus approximate the relationship between overland flow intensity and sediment transport capacity. Values in the range of 1.0 to 2.5 have been used on the limited number of watersheds tested to date. The most common values are between 1.6 and 2.0 but initial values should be checked through calibration.

KSER,
KEIM: These parameters are the coefficients in the sediment washoff, or transport, equation. They represent an attempt to combine the effects of (1) slope, (2) overland flow length, (3) sediment particle size, and (4) surface roughness on sediment transport capacity of overland flow into a single calibration parameter. Consequently, at the present time calibration is the major method of evaluating both KSER and KEIM. Land surface conditions will have a significant effect on KSER. Limited experience to date has indicated a possible range of values of 0.01 to 5.0. However, significant variations from this can be expected.

SRERI,
TSI: These parameters indicate the amount of detached soil fines (sediment) on the land surface of pervious (SRERI) and impervious (TSI) areas at the beginning of the simulation period. Very little research or experience relates to the estimation of these parameters especially on pervious areas. Estimation of these parameters is closely tied to the calibration process discussed in Section A6.

Table 38. COMPUTED K VALUES FOR SOILS ON EROSION-RESEARCH STATIONS

Soil	Source of data	Computed K
Dunkirk silt loam	Geneva, N.Y.	0.69[a]
Keene silt loam	Zanesville, Ohio	.48
Shelby loam	Bethany, Mo	.41
Lodi loam	Blacksburg, Va	.39
Fayette silt loam	LaCrosse, Wis	.38[a]
Cecil sandy clay loam	Watkinsville, Ga	.36
Marshall silt loam	Clarinda, Iowa	.33
Ida silt loam	Castana, Iowa	.33
Mansic clay loam	Hays, Kans	.32
Hagerstown silty clay loam	State College, Pa	.31[a]
Austin clay	Temple, Tex	.29
Mexico silt loam	McCredie, Mo	.28
Honeoye silt loam	Marcellus, N.Y.	.28[a]
Cecil sandy loam	Clemson, S.C.	.28[a]
Ontario loam	Geneva, N.Y.	.27[a]
Cecil clay loam	Watkinsville, Ga	.26
Boswell fine sandy loam	Tyler, Tex	.25
Cecil sandy loam	Watkinsville, Ga	.23
Zaneis fine sandy loam	Guthrie Okla	.22
Tifton loamy sand	Tifton, Ga	.10
Freehold loamy sand	Marlboro, N.J.	.08
Bath flaggy silt loam with surface stones 2 inches removed.	Arnot, N.Y.	.05[a]
Albia gravelly loam	Beemerville, N.J.	.03

[a]Evaluated from continuous fallow. All others were computed from row-crop data.

Source: Wischmeier and Smith (54), p. 5

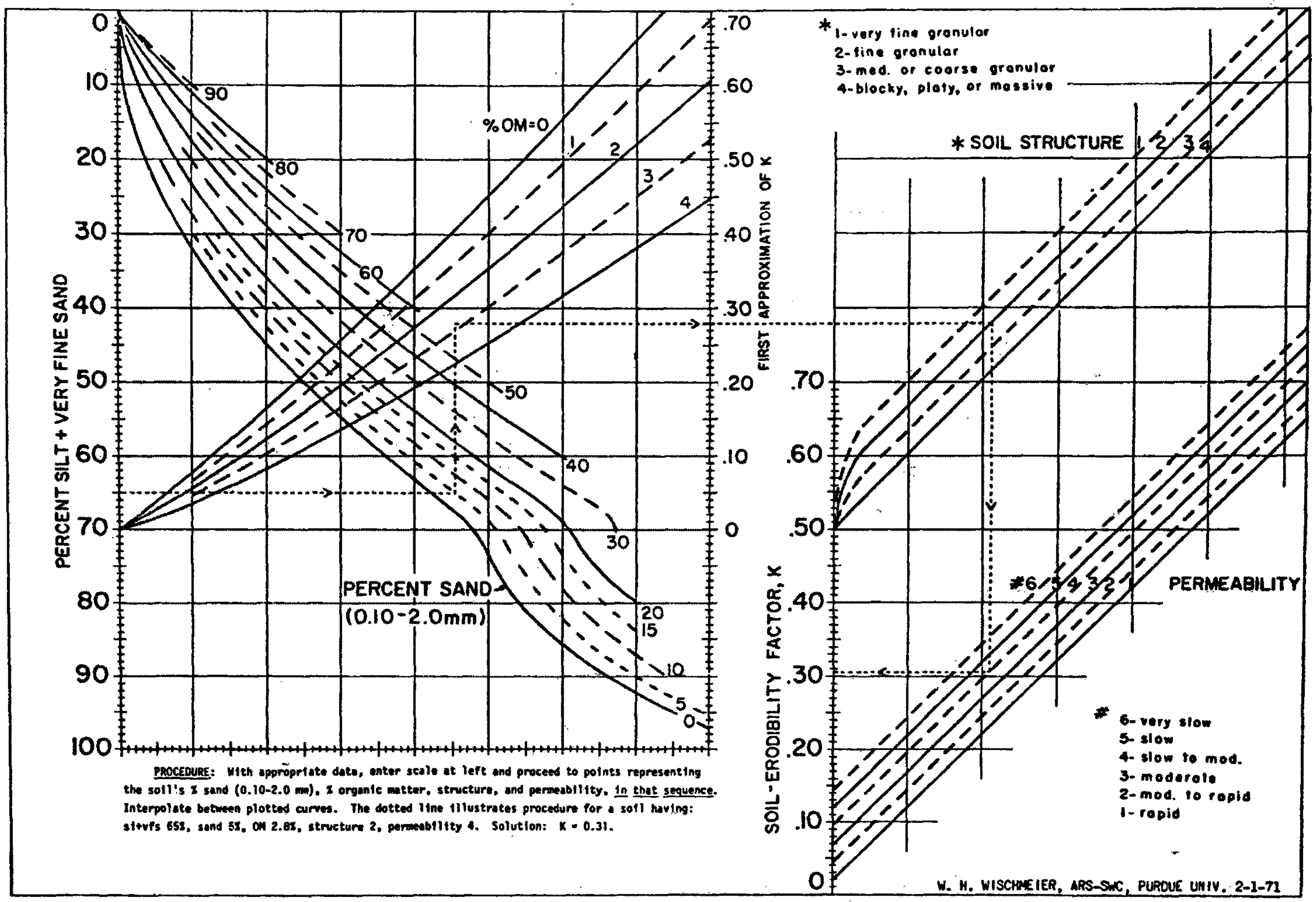

Figure 36. Soil Erodibility Nomograph

Source: Wischmeier, Johnson, and Cross (74), p. 190

COVVEC: This parameter is the percent land cover on pervious areas of the watershed, and is used to decrease the fraction of the land surface that is susceptible to soil fines detachment by raindrop impact. Twelve monthly values for the mid-point of each month are input to the Model, and the cover on any day is determined by linear interpolation. COVVEC values can be evaluated as one minus the C factor in the Universal Soil Loss Equation, i.e., COVVEC = 1 - C, when C is a monthly value. Evaluation methods for the C factor have been published in the literature (51, 78). Tables 39 and 40 pertain to the evaluation of C on undisturbed lands and have been reproduced from the paper by Wischmeier (78). C factors for disturbed lands (cropland, agriculture, and construction areas) have been published in the USLE Report (51). The user should refer to both of these cited references for an understanding of the factors considered in the evaluation of land cover.

ARFRAC,
IMPKO: These parameters are evaluated for each land use. They represent the fraction of the total watershed in a particular land use (ARFRAC) and the impervious fraction of that land use (IMPKO). The impervious area fraction includes only impervious areas directly connected to a drainage path or channel. Land use and topographic maps are the major source of information for evaluating ARFRAC and IMPKO. Correlation equations for estimating imperviousness, curb length, and other land use factors from socioeconomic data have been published (79, 80). However, the general reliability of these correlations is unknown. They should be used with caution and only if no relevant data is available for the watershed.

ACUP, ACUPV, ACUI,
ACUIV: These parameters represent the daily sediment accumulation rates from land use activities on pervious (ACUP, ACUPV) and impervious (ACUI, ACUIV) areas. If monthly variations are specified, 12 values must be input for both ACUPV (pervious) and ACUIV (impervious). On the other hand, only single values for ACUP (pervious) and ACUI (impervious) are required if average annual accumulation rates are used. Table 41 summarizes the available data on sediment (or Total Solids) accumulation rates for various cities across the country. The data in Table 41 pertains to impervious areas since it was collected on street surfaces. Logically, one would expect impervious areas to experience larger accumulation rates than pervious areas because of the predominant concentration of pollutant-generating activities around impervious surfaces (streets, parking lots, buildings, etc.). However very little

Table 39. C VALUES FOR PERMANENT PASTURE, RANGELAND, AND IDLE LAND[a]

Canopy: Type and height[b] (1)	Canopy: Pct cover[c] (2)	Type[d] (3)	Ground cover, Pct cover: 0 (4)	20 (5)	40 (6)	60 (7)	80 (8)	95–100 (9)
None	...	G	0.45	0.20	0.10	0.042	0.012	0.003
		W	.45	.24	.15	.091	.043	.011
Weeds or short brush (0.5 m).	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Brush or bushes (2 m).	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, no low brush (4 m).	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.013	.003
		W	.36	.20	.13	.084	.041	.011

[a] All values assume (1) random distribution of mulch or vegetation, and (2) mulch of substantial depth where credited.
[b] Classified by average fall height of waterdrops from canopy to soil surface, in meters.
[c] Percentage of total-area surface that would be hidden from view by canopy in a vertical projection.
[d] G—Cover at surface is grass or decaying, compacted duff of substantial depth. W—Cover at surface is weeds (plants with little lateral-root network near the surface) or undecayed residue.

Table 40. C FACTORS FOR WOODLAND

Stand condition	Tree canopy (pct of area)[a]	Forest litter (pct of area)[b]	Undergrowth[c]	C-Factor
Well stocked	100–75	100–90	Managed[d]	0.001
			Unmanaged	.003–0.011
Medium stocked	75–40	90–75	Managed	.002– .004
			Unmanaged	.01– .04
Poorly stocked	40–20	70–40	Managed	.003– .009
			Unmanaged	.02– .09[e]

[a] Area with tree canopy over less than 20 pct will be considered grassland or cropland for estimating soil loss (table 2).
[b] Forest litter is assumed to be of substantial depth over the percent of the area on which it is credited.
[c] Undergrowth is defined as shrubs, weeds, grasses, vines, etc. on the surface area not protected by forest litter. Usually found under canopy openings.
[d] Managed—Grazing and fires are controlled. Unmanaged—Stands that are overgrazed or subjected to repeated burning.
[e] For unmanaged woodland with litter cover of less than 75 pct, C-values should be derived by taking 0.7 of the appropriate values in table 2. The factor of 0.7 adjusts for the much higher soil organic matter on permanent woodland.

Source: Wischmeier and Smith (74), pp. 123-24

Table 41. REPRESENTATIVE SEDIMENT ACCUMULATION RATES FOR VARIOUS LAND USES AND LOCATIONS[a, c]

Land Use	Sediment Accumulation (lb/acre/day)							
	S Jose I	S Jose II	Phoenix I	Phoenix II	Tulsa	Seattle	Baltimore	Atlanta
Residential[b]:								
low/old/single	23	51	21	16	1	32		187
lod/old/multi	29	5	51	14		25	23	
medium/new/single	8	4	5	4	58		23	98
median/old/multi	-	-	9	5	14	11	-	13
Industrial:								
light	44	68	12	3	63	54	27	-
medium	20	7	36	15	21	-	18	-
heavy	-	-	-	-	-	-	5	124
Commercial:								
suburban shopping	8	9	17	2	16	13	1	22
central business	7	1	6	2	10	15	2	159
Weighted Mean	29	8	31	9	22	23	18	102
Sampling Time	12/70	6/71	1/71	6/71	6/71	7/71	5/71	6/71

Notes:

a. These values should be used only as guidelines. They are based on a single sampling period in each of the locations and are derived from loading intensities published in Table 3 of Sartor and Boyd (50) divided by the estimated time since the last storm as shown in Appendix B of that report.

b. For residential land: low or medium density/old or new area/single or multi housing

c. For comparison purposes, the values used in the NPS Model testing were as follows:
   Durham, North Carolina (mixed urban land use): 30 -80 lb/ac/day
   Madison, Wisconsin (residential): 1.2 lb/ac/day
   Seattle, Washington (commercial): 1.5 lb/ac/day

information is presently available to quantify the difference in accumulation rates between pervious and impervious areas.

If data on accumulation rates are available for the watershed, they should be used in place of the values shown in Table 41. Differences in socioeconomic factors, types of activities in each land use, and climate influence accumulation rates; thus, data for the specific site or in a nearby area should be used to the extent possible. Often accumulation rates are presented in terms of pounds per day per mile of curb length. Curb length per acre must be estimated to convert these rates to the units required by the NPS Model (lb/day/acre). The correlation equations mentioned above (79, 80) may be used to estimate the conversion factor if no other data is available. Values of accumulation rates estimated from Table 41 or from specific watershed data will need to be verified through calibration.

REPER, REPERV,
REIMP, REIMPV: These parameters refer to the removal of sediment from pervious (REPER, REPERV) and impervious (REIMP, REIMPV) areas by processes other than runoff. As with accumulation rates either monthly variations (REPERV, REIMPV) or average annual values (REPER, REIMP) can be specified. On pervious areas these removal processes will include wind, air currents from traffic, and possibly consolidation/aggregation of sediments to larger particles less susceptible to transport by overland flow. On impervious areas street cleaning activities must be included in the above list. The removal rates are expressed as the fraction of sediment (or Total Solids) removed per day. Very little information is available for evaluation of removal rates. Values for removal rates from pervious areas may range from 0.01 to 0.10 largely as a function of wind and associated air currents. For impervious areas, the effects of street cleaning should be added to the wind component and can be estimated as

$$R = P*(E/D) \tag{28}$$

where R = sediment removal from impervious areas by street cleaning
P = fraction of impervious area on which street cleaning is performed
E = efficiency of street cleaning
D = frequency of street cleaning

Thus, if street cleaning is performed every five days on 40 percent of the impervious area with an efficiency of 80 percent, then

$$R = (.40)(.80)/(5) = 0.0512 \qquad (32)$$

If wind removal is estimated as 0.02, then REIMP would be approximately 0.07 and REPER would be 0.02. In essence the removal rates are evaluated in conjunction with accumulation rates to establish a limit to the total sediment accumulation that can occur. As indicated in Section VII, this limit for impervious areas would be 1/REIMP days of accumulation. Consequently, joint calibration of accumulation and removal rates is required.

PMPVEC, PMPMAT
PMIVEC, PMIMAT: These parameters are the potency factors specifying the pollutant content of sediment washed from pervious (PMPVEC, PMPMAT) and impervious (PMIVEC, PMIMAT) areas. As with accumulation and removal rates, the user can specify 12 monthly potency factors (PMPMAT, PMIMAT) for each pollutant simulated or use an average annual potency factor (PMPVEC, PMIVEC) for each pollutant. Table 42 summarizes the most relevant available data for the evaluation of potency factors for various pollutants and land uses. Obviously, any available water quality data on the watershed should be used to evaluate and adjust the potency factors obtained from Table 42. Pollutant concentrations divided by sediment (or TS) concentrations, on a storm or single sample basis, will provide estimates of potency factors. Although large variations may exist in potency factors obtained from recorded data, relatively stable relationships can be found when the recorded data is categorized by land use and season (or time) of the year.

Table 42. REPRESENTATIVE POTENCY FACTORS FOR BOD , COD, AND SS FOR VARIOUS LAND USES AND LOCATIONS

Land Use/Location		Potency Factors (% of sediment)		
		BOD	COD	SS
Residential:	Low/old/single	0.86	2.70	15
	Low/old/multi	2.00	2.30	20
	Medium/new/single	1.06	3.54	25
	Medium/old/multi	0.77	2.62	20
Industrial:	Light	1.70	8.26	20
	Medium	1.11	5.89	30
	Heavy	0.33	1.49	40
Commercial:	Suburban shopping	0.86	2.07	20
	Central business	0.86	3.11	30
Sites Sampled by Sartor and Boyd (50):				
	San Jose I	1.70	34.00	
	Phoenix I	1.00	4.60	
	Milwaukee	0.44	1.80	9.2
	Bucyrus	0.21	2.10	46.2
	Baltimore	6.10	2.00	29.5
	San Jose II	0.89	6.80	
	Atlanta	0.45	3.00	18.2
	Tulsa	4.30	9.10	14.7
	Phoenix II	1.10	5.80	
	Seattle	1.00	3.80	
numerical mean		1.70	7.30	
average deviation		1.30	6.80	
NPS Model Test Sites:				
	Durham, North Carolina	4.0		71.0
	Seattle, Washington	3.6		38.0

Notes:
1. For residential land use: low or median density/old or new area/single or multi housing
2. These values should be used only as guidelines for estimation of initial values of potency factors. Water quality data on the watershed should pre-empt the table values.
3. The BOD and COD potency factors for the individual land uses and cities were obtained from Tables 7 and C-7 in Sartor and Boyd (50).
4. The SS potency factors for the individual cities were obtained from Table 5 in Sartor and Boyd (50) assuming SS are particle sizes less than 104 microns, while those for the separate land uses are gross estimates based on the judgment of the authors. Specific sites may vary significantly from the above values.

A6. CALIBRATION PROCEDURES AND GUIDELINES

Calibration has been repeatedly mentioned throughout this report and user manual; this indicates the importance of the calibration process in application of the NPS Model. At the risk of further repetition, the calibration process will be defined and described in this section and recommended procedures and guidelines will be presented. The goal is to provide a general calibration methodology for potential users of the NPS Model. As one gains experience in calibration, the methodology will become second-nature and individual methods and guidelines will evolve.

Calibration is an iterative procedure of parameter evaluation and refinement by comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically evaluated from topographic, climatic, edaphic, or physical/chemical characteristics. Fortunately, the large majority of NPS parameters do not fall in this category. Calibration should be based on several years of simulation (3 to 5 years is optimal) in order to evaluate parameters under a variety of climatic, soil moisture, and water quality conditions. The areal variability of meteorologic data series, especially precipitation and air temperature, may cause additional uncertainity in the simulation. Years with heavy precipitation are often better simulated because of the relative uniformity of large events over a watershed. In contrast low annual runoff may be caused by a single or a series of small events that did not have a uniform areal coverage. Parameters calibrated on a dry period of record may not adequately represent the processes occurring during wet periods. Also, the effects of initial conditons of soil moisture and pollutant accumulation can extend for several months resulting in biased parameter values calibrated on short simulation periods. Calibration should result in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period.

Calibration includes the comparison of both monthly and annual values and individual storm events. Both comparisons should be performed for a proper calibration of hydrology and water quality parameters. Hydrologic calibration must preceed sediment and water quality calibration since runoff is the transport mechanism by which nonpoint pollution occurs. The steps in the overall calibration process for the NPS Model are:

(1) Estimate initial values for all parameters from the guidelines provided.

(2) Perform hydrologic calibration run (HYCAL=1).

(3) Compare simulated monthly and annual runoff volumes with recorded data.

(4) Adjust hydrologic calibration parameters, and initial conditions if necessary, to improve agreement between simulated monthly and annual runoff and recorded values.

(5) Repeat steps 2, 3, and 4 until satisfactory agreement is obtained.

(6) Compare simulated and recorded hydrographs for selected storm events.

(7) Adjust hydrologic calibration parameters to improve storm hydrograph simulation.

(8) Perform additional calibration runs and repeat step 7 until satisfactory storm simulation is obtained while maintaining agreement in the monthly and annual runoff simulation.

(9) Perform calibration run for sediment parameters (HYCAL=2).

(10) Compare simulated monthly and annual sediment loss with recorded values, if available.

(11) Compare simulated storm sediment graphs with recorded values for selected events.

(12) Adjust sediment calibration parameters to improve the simulation of monthly and annual values and storm sediment graphs.

(13) Repeat steps 9, 10, 11, and 12 until satisfactory sediment simulation is obtained.

(14) Compare simulated monthly and annual pollutant loss with recorded values, if available.

(15) Compare simulated and recorded pollutant graphs (concentration and/or mass removal) with recorded data for selected events.

(16) Adjust pollutant potency factors and perform additional pollutant calibration trials until satisfactory agreement is obtained.

At the completion of the above steps, the NPS Model is calibrated to the watershed being simulated under the land use conditions in effect during the calibration period. Production runs can be performed (HYCAL=3 or 4) for existing conditions or projected future conditions for evaluation of nonpoint pollution problems. Often times, sufficient data will not be available to complete all steps in the calibration process. For example, monthly and annual values of sediment or pollutants will not be available for comparison with simulated results. In these circumstances, the user may omit the corresponding steps in calibration; however, simulated values should be analyzed and evaluated with respect to data from similar watersheds, personal experience, and guidelines provided below.

Hydrologic Calibration

Hydrologic simulation combines the physical characteristics of the watershed geometry and the observed meteorologic data series to produce the simulated hydrologic response. All watersheds have similar hydrologic components, but they are generally present in different combinations; thus different hydrologic responses occur on individual watersheds. The NPS Model simulates runoff from four components: surface runoff from impervious areas directly connected to the channel network, surface runoff from pervious areas, interflow from pervious areas, and ground water flow. Since the historic streamflow is not divided into these four units, the relative relationship among these components must be inferred from the examination of many events over several years of continuous simulation. Periods of record with a predominance of one component (e.g., surface runoff during storm periods, or ground water flow after extended dry periods) can be studied to evaluate the simulation of the individual runoff components.

The first task in hydrologic calibration is to establish a water balance on an annual basis. This balance specifies the ultimate destination of incoming precipitation and is indicated as

$$\text{Precipitation} - \text{Actual Evapotranspiration} - \text{Deep percolation} - \Delta\text{Soil Moisture Storage} = \text{Runoff} \qquad (30)$$

In addition to the input meteorologic data series, the parameters that govern this balance are LZSN, INFIL, and K3 (evapotranspiration index parameter). Thus, if precipitation is measured on the watershed and if deep percolation to ground water is small, actual evapotranspiration must be adjusted to cause a change in the long-term runoff component of the water balance. LZSN and INFIL have a major impact on percolation and are important in obtaining an annual water balance. In addition, on extremely small watersheds (less than 100-200 hectares) that contribute runoff only during and immediately following storm events, the UZSN parameter can also affect annual runoff volumes because of its impact on individual storm events (described below).

Recommendations for obtaining an annual water balance are as follows:

(1) Annual precipitation should be greater than or equal to the sum of annual evaporation plus annual runoff if ground water recharge through deep percolation is not significant in the watershed. If this does not occur the K1 parameter should be re-evaluated (see Section A5) and adjusted to insure that the input precipitation is indicative of that occurring on the watershed.

(2) Since the major portion of actual evapotranspiration occurs from the lower soil moisture zone, increasing LZSN will increase actual evapotranspiration and decrease annual runoff. Also, decreasing LZSN will reduce actual evapotranspiration and increase annual runoff. Thus, LZSN is the major parameter for deriving an annual water balance.

(3) Actual evapotranspiration is extremely sensitive to K3. Since K3 is evaluated as the fraction of the watershed with deep rooted vegetation, increasing K3 will increase actual evapotranspiration and vice versa. Thus, minor adjustments in K3 may be used to effect changes in annual runoff if actual evapotranspiration is a significant hydrologic component in the watershed.

(4) The INFIL parameter can also assist in deriving an annual water balance although its main effect is to adjust the seasonal, or monthly runoff distribution described below. Since INFIL governs the division of precipitation into various components, increasing INFIL will decrease surface runoff and increase the transfer of water to lower zone and ground water. The resulting increase in water in the lower zone will produce higher actual evapotranspiration. Decreasing INFIL will generally reduce actual evapotranspiration and increase surface runoff. In watersheds with no baseflow component (from ground water), INFIL can be used in conjuction with LZSN to establish the annual water balance.

When an annual water balance is obtained, the seasonal or monthly distribution of runoff can be adjusted with use of the INFIL parameter. INFIL, the infiltration parameter, accomplishes this seasonal distribution by dividing the incoming moisture among surface runoff, interflow, upper zone soil moisture storage, percolation to lower zone soil moisture, and ground water storage. Of the various hydrologic components, ground water is often the easiest to identify. In watersheds with a continuous baseflow, or ground water component, increasing INFIL will reduce immediate surface runoff (including interflow) and increase the ground water component. In this way, runoff is delayed and occurs later in the season as an increased ground water, or base flow. Decreasing INFIL will produce the opposite result. Although INFIL and

LZSN control the volume of runoff from ground water, the KK24 parameter controls the rate of outflow from the ground water storage.

In watersheds with no ground water component, the K24L parameter is used to direct the ground water contributions to deep inactive ground water storage that does not contribute to runoff (K24L = 1.0 in this case). For these watersheds, runoff cannot be transferred from one season or month to another, and the INFIL parameter is used in conjunction with LZSN to obtain the annual and individual monthly water balance.

Continuous simulation is a prerequisite for correct modeling of individual events. The initial conditions that influence the magnitude and character of events are the result of hydrologic processes occurring between events. Thus, the choice of initial conditions for the first year of simulation is an important consideration and can be misleading if not properly selected. The initial values for UZS, LZS, and SGW should be chosen according to the guidelines in Section A5 and readjusted after the first calibration run. UZS, LZS, and SGW for the starting day of simulation should be reset approximately to the values for the corresponding day in subsequent years of simulation. Thus, if simulation begins in October, the soil moisture conditions in subsequent Octobers in the calibration period can usually be used as likely initial conditions for the simulation. Meteorologic conditions preceeding each October should also be examined to insure that the assumption of similar soil moisture conditions is realistic.

When annual and monthly runoff volumes are adequately simulated, hydrographs for selected storm events can be effectively altered with the UZSN and INTER parameters to better agree with observed values. Also, minor adjustments to the INFIL parameter can be used to improve simulated hydrographs; however, adjustments to INFIL should be minimal to prevent disruption of the established annual and monthly water balance. Parameter adjustment should be concluded when changes do not produce an overall improvement in the simulation. One event should not be matched at the expense of other events in the calibration period.

Recommended guidelines for adjustment of hydrograph shape are as follows:

(1) The interflow parameter, INTER, can be used effectively to alter hydrograph shape after storm runoff volumes have been correctly adjusted. INTER has a minimal effect on runoff volumes. As shown in Figure 37 where the values of INTER were (a) 1.4, (b) 1.8, and (c) 1.0, increasing INTER will reduce peak flows and prolong recession of the hydrograph. Decreasing INTER has the opposite effect. On large watersheds where storm events extend over a number of days, the IRC parameter (see Section A5) can be used to

adjust the recession of the interflow portion of the hydrograph to further improve the simulation.

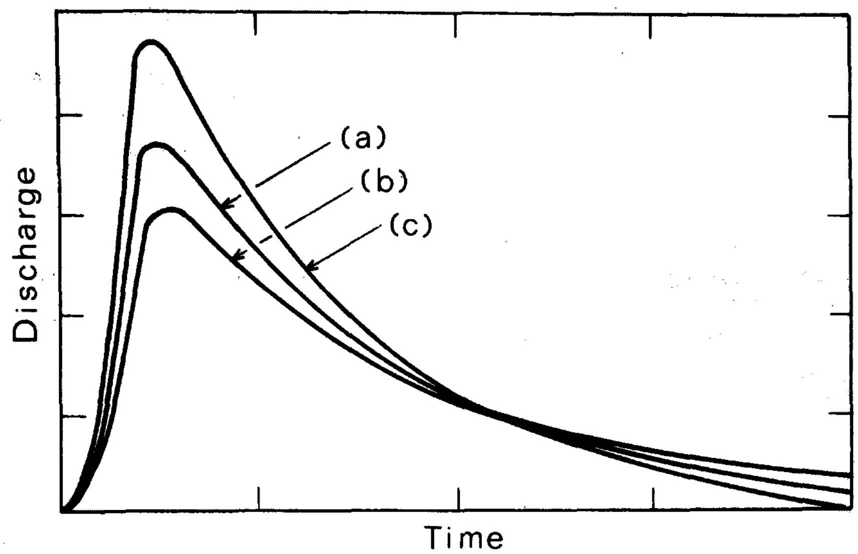

Figure 37. Example of the response to the INTER parameter

(2) The UZSN parameter also affects hydrograph shape. Decreasing UZSN will generally increase flows especially during the initial portions, or rising limb, of the hydrograph. Low UZSN values are indicative of highly responsive watersheds where the surface runoff component is dominant. Increasing UZSN will have the opposite effect, and high UZSN values are common on watersheds with significant subsurface flow and interflow components. Caution should be exercised when adjusting hydrograph shape with the UZSN parameters to insure that the overall water balance is not significantly affected.

(3) The INFIL parameter can be used for minor adjustments to storm runoff volumes and distribution. Its effects have been discussed above. As with UZSN, changes to INFIL can affect the water balance; thus, modifications should be minor.

When the calibration of storm hydrographs is completed, the entire hydrologic calibration is finished, and sediment and water quality calibration can be initiated.

Sediment and Water Quality Calibration

As indicated in the description of the calibration process, sediment calibration follows the hydrologic calibration and must preceed the adjustment of the pollutant potency factors in water quality calibration.

Sediment parameter calibration is more uncertain than hydrologic calibration due to less experience with sediment simulation in different regions of the country. The process is analogous; the major sediment parameters are modified to increase agreement between simulated and recorded monthly sediment loss and storm event sediment removal. However, observed monthly sediment loss is often not available, and the sediment calibration parameters are not as distinctly separated between those that affect monthly sediment and those that control storm sediment loss. In general, sediment calibration involves the development of an approximate equilibrium or balance between the accumulation and generation of sediment particles on one hand and the washoff or transport of sediment on the other hand. Thus, the accumulated sediment on the land surface should not be continually increasing or decreasing throughout the calibration period. Extended dry periods will produce increases in surface pollutants, and extended wet periods will produce decreases. However, the overall trend should be relatively stable. This equilibrium must be developed on both pervious and impervious surfaces, and must exist in conjuction with the accurate simulation of monthly and storm event sediment loss. The accumulated sediment on pervious and impervious areas is printed in the monthly and annual summaries and at the beginning of each storm event (for HYCAL=2). To assist in sediment calibration, the following guidelines are extended:

(1) On pervious areas, KRER, ACUP, and REPER are the major parameters that control the availability of sediment on the land surface, while KSER and JSER control the sediment washoff. The daily accumulation and removal of sediments by ACUP and REPER will dominate sediment availability for land surfaces with high cover factors (COVVEC). On exposed land surfaces, sediment generation by soil splash is important and is controlled largely by the KRER parameter. To offset the sediment availability on pervious areas, the KSER and JSER parameters control sediment washoff to prevent continually increasing or decreasing sediment on the land surface. Thus, a balance must be established between the KRER, ACUP, and REPER parameters and the KSER and JSER parameters to develop the equilibrium described above.

(2) On impervious areas, soil splash is not significant. The major sediment accumulation and removal parameters are ACUI and REIMP,

and the sediment washoff parameters are KEIM and JEIM. These two parameter sets must be adjusted to maintain a relatively stable amount of sediment on impervious surfaces throughout the calibration period.

(3) The calibration output indicates the flow contributions from pervious and impervious surfaces and pollutant contributions from pervious and impervious surfaces in each land use simulated (see Section A4). In urban areas, the majority of nonpoint pollutants will emanate from impervious land surfaces especially during small storm events and in the early portion of extended events. Pervious land surfaces in urban areas will generally contribute a significant amount of pollutants only during large storm events and the latter portion of extended events. The user should note this behavior from the output provided during calibration runs.

(4) The output from the NPS Model indicates the accumulated sediment on pervious and impervious surfaces in each land use. This information is provided at the beginning of each storm event (for HYCAL=2 or 3) and in the monthly and annual summaries to assist in the development of the sediment balance.

(5) The daily removal factors, REPER and REIMP, are usually assumed to be relatively constant and fixed. Also, the exponents of soil splash (JRER) and sediment washoff (JSER, JEIM) are reasonably well defined. Thus, the parameters that receive major consideration during sediment calibration are: the accumulation rates, ACUP and ACUI; the coefficient of soil splash, KRER (especially for exposed land surfaces); and the coefficients of sediment washoff, KSER and KEIM.

(6) In general, an increasing sediment storage throughout the calibration period indicates that either accumulation and soil fines generation is too high, or sediment washoff is too low. Examination of individual events will confirm whether or not sediment washoff is under-simulated. Also, the relative contributions of pervious and impervious surfaces will help to determine whether the pervious or impervious washoff parameters should be modified. A continually decreasing sediment storage can be analyzed in an analogous manner.

(7) The sediment washoff during each simulation interval is equal to the smaller of two values; the transport capacity of overland flow or the sediment available for transport from pervious or impervious surfaces in each land use. To indicate which condition is occurring, an asterisk (*) is printed in the calibration output whenever sediment washoff is limited by the accumulated sediment

(see Table 28). Thus, when no asterisks are printed washoff is occurring at the estimated transport capacity of overland flow. Generally, washoff will be at capacity (no asterisks) during the beginning intervals of a significant storm event; this simulates the "first flush" effect observed in many nonpoint pollution studies. As the surface sediment storage is reduced, washoff will be limited by the sediment storage during the latter part of storm events. However, for very small events overland flow will be quite small and washoff can occur at capacity throughout. Also, on agricultural and construction areas washoff will likely occur at capacity for an extended period of time due to the large amount of sediment available for transport.

(8) Using the information provided by the asterisks (described above) minor adjustments in JRER, JSER, and JEIM can be used to alter the shape of the sediment graph for storm events. For pervious areas when available sediment is limiting (asterisks printed), increasing JRER will tend to increase peak values and decrease low values in the sediment graph. Decreasing JRER will have the opposite effect tending to decrease the variability of simulated values. When sediment is not limiting (no asterisks printed), the JSER parameter will produce the same effect. Increasing JSER will increase variability while decreasing it will decrease variability.

    For impervious areas, the JEIM parameter will produce the effects described above when sediment washoff from impervious areas is occurring at the transport capacity. All these parameters will also influence the overall sediment balance, but if parameter adjustments are minor, the impact should not be significant.

Both sediment and water quality calibration should be performed on a single land use at a time, if possible, in order to correctly evaluate contributions from individual land uses. However, the calibration output does indicate the individual land use contributions so that the user can implicitly evaluate the distribution for reasonableness.

When the sediment calibration is completed, adjustments in the pollutant potency factors can be performed. Generally, monthly and annual pollutant loss will not be available, so the potency factors will be adjusted by comparing simulated and recorded pollutant concentrations, or mass removal, for selected storm events. For nonpoint pollution, mass removal in terms of pollutant mass per unit time (e.g., gm/min) is often more indicative of the washoff mechanism than instantaneous observed pollutant concentrations. However, the available data will often govern the type of comparison performed.

Storms that are well simulated for both flow and sediment should be used for calibrating the potency factors. The initial values of potency factors should be increased if pollutant graphs are uniformly low and decreased if the graphs are uniformly high. Monthly variations in potency factors can be used for finer adjustments of simulation in different seasons if sufficient evidence and information is available to indicate variations for the specific pollutant. However, individual storms should not be closely matched at the expense of the other storms in the season. Also, consistency between the sediment and pollutant simulation is important; if sediment is under-simulated then the pollutant should be under-simulated, and vice versa. Inconsistent simulations can indicate that sediment is not a transport mechanism for the particular pollutant or that the potency factors have been incorrectly applied. Also, if there is no similarity between the shapes of the recorded sediment and pollutant graphs, then pollutant transport is not directly related to sediment transport and no amount of adjustment will allow an effective simulation of that pollutant.

Conclusion

The use of a continuous simulation model provides insight into the relationships among the various components in the hydrologic cycle and nonpoint source pollution. A model cannot be applied without understanding these relationships, yet the process of modeling itself is instructive in developing this understanding. The calibration process described above requires such an understanding of the physical process being simulated, the method of representation, and the impact of critical NPS Model parameters. It is not a simple procedure. However, study of the parameter definitions, the algorithm formulation, and the above guidelines should allow the user to become reasonably effective in calibrating and applying the NPS Model.

A7. COMPUTER AND MANPOWER REQUIREMENTS

The NPS Model is written in the IBM FORTRAN IV language and was developed and run on the Stanford University IBM 360/67 and 370/168 computers. The 'handy minimal language' concept (81) was adopted to the extent possible to produce a reasonably compatible computer code for at least the following computer systems: IBM 360, UNIVAC 1108, CDC 6000, and Honeywell Series 32. However, at the present time, Model operation has been limited to the Stanford IBM systems. The NPS Model operates most efficiently in a two-step procedure. The first step involves the compilation of the program and the storage of the compiled version on disk or magnetic tape. In step two the compiled Model is provided the necessary input data and is executed. Thus, the Model can operate a number of types of different input data with a single compilation.

Representative time and core requirements for compilation and execution of the NPS Model on the Stanford systems (FORTRAN G Compiler) are shown below.

	Central Processor Unit Time (minutes)	Computer Core Requirements (bytes)
Compilation		
IBM 360/67	2.5	194 K
IBM 370/168	0.5	124 K
Execution		
Hydrologic Calibration (HYCAL=1)		
IBM 360/67	2.0/year	128 K
IBM 370/168	0.5/year	136 K
Sediment & Water Quality Calibration (HYCAL=2)		
IBM 360/67	4.7/year	128 K
IBM 370/168	0.5/year	136 K
Production Run (HYCAL=4)		
IBM 360/67	2.8/year	142 K
IBM 370/168	0.6/year	144 K

Execution time requirements are based on simulation runs for the Durham, North Carolina watershed including simulation of four land use categories and two water quality constituents, in addition to water temperature and dissolved oxygen. Substantial time reductions occur when sediment and water quality simulation is performed for fewer land uses and/or constituents. Also, simulation of snow accumulation and melt will increase computer time approximately 20 to 30 percent.

The manpower effort required to use and apply the NPS Model will vary considerably with the level of technical personnel, the data availability, and the length of the simulation period. Considerable economies of scale are introduced in personnel requirements when longer simulation periods are utilized. The estimates below for the necessary tasks in applying the NPS Model assume an individual with a bachelor's degree in a technical field with 2 to 3 years experience in water resource and water quality related work. These estimates further assume a reasonable level of technician support.

Task	Estimated Person-Weeks
(1) Familiarization with NPS Model report and user manual	2.5
(2) Data collection and analysis	1.0/year of simulation
(3) Preparation of Model input sequence of meteorologic data	1.5/year of simulation
(4) Parameter evaluation	1.0
(5) Calibration (hydrology, sediment, and water quality)	3.0/year of calibration

These values should be used only as approximate guidelines; extended simulation periods will allow reductions in the above "per year" estimates. On the other hand peculiar problems in data availability and calibration could expand the required effort. Personnel requirements for production runs and simulation of various land use alternatives need to be added to the above values. In essence, these estimates only indicate that the NPS Model cannot be adequately applied in a short time span of 2 to 3 weeks; however, application does not require an extensive 1 to 1.5 year effort.

APPENDIX B

HYDROLOGIC (LANDS) SIMULATION ALGORITHMS

This appendix reviews the equations or algorithms used in the simulation of hydrologic processes in the LANDS subprogram of the NPS Model. Except for the numbering of equations and figures, the following discussion is abstracted directly from the corresponding sections of the Hydrocomp Simulation Programming (HSP) Operations Manual (23). The potential user of the NPS Model should thoroughly understand the Model representation of the hydrologic processes and the importance of Model parameters prior to attempting application and calibration of the NPS Model. The flowchart of the LANDS subprogram was shown in Figure 3 of the report, and the LANDS parameters are shown in capital letters in the algorithm descriptions below.

INTERCEPTION

The first loss to which falling precipitation is subjected is interception or retention on leaves, branches, and stems of vegetation. Interception in any single storm is small in amount and is not important in flood-producing storms. However, in the aggregate interception may have a significant effect on annual runoff volumes.

In nature, interception is a function of the type and extent of vegetation and, for deciduous vegetation, the season of the year. In the NPS Model interception is modeled by defining an interception storage capacity EPXM as an input parameter. All precipitation is assumed to enter interception storage until it is filled to capacity. Water is removed from interception storage by evapotranspiration at the potential rate. Evapotranspiration may occur even during rain so that after the storage is filled there is a continuing interception equal to the potential evapotranspiration.

IMPERVIOUS AREA

Precipitation on impervious areas that are adjacent to or connected with stream channels will contribute directly to surface runoff. The "impervious" fraction of the total watershed area is calculated in the NPS Model from the impervious fraction of each land use and the land use area. Precipitation minus interception is multiplied by the impervious area fraction to determine the impervious area contribution to streamflow. In simulating the effects of impervious areas, small losses result from the film of water retained on the impervious surface after a rain, and the continuing exposure of water on the impervious area to evapotranspiration. Rock outcrops, buildings, or roads that are so located that runoff from them must flow over soil before reaching a channel should not be counted in the impervious area. Such runoff is represented by the direct infiltration functions in the model.

The impervious area is usually a very small percentage of the total watershed except in urban areas where the impervious area term becomes very important. In rural watersheds impervious area does not contribute large amounts of runoff. However, for light rains with relatively dry soil, the impervious area may be the sole contributor to runoff to the stream. During the calibration phase the impervious area term is useful in reproducing these small runoff events and enhances the detailed understanding of the hydrologic process during simulation.

Calculations in the LANDS subprogram are carried in terms of water depth (inches or millimeters) over a unit area. When concentrations of quality constituents and flow rates are required, these depths are multiplied by the area and divided by the time interval to derive actual volumes and rates of runoff.

INFILTRATION

The process of infiltration is essential and basic to simulation of the hydrologic cycle. Infiltration is the movement of water through the soil surface into the soil profile. Infiltration rates are highly variable and change with the moisture content of the soil profile. Infiltration is the largest single process diverting precipitation from immediate streamflow. Usually more than half of the water which infiltrates is retained in the soil until it is returned to the atmosphere by evapotranspiration. However, not all infiltrated water is permanently diverted from streamflow. Some infiltrated water may move laterally through the upper soil to the stream channel as interflow, and some may enter temporary storages and later discharge into the stream channel as base or ground water flow.

Water which does not infiltrate directly into the soil moves over the land surface and is subject to delayed infiltration and retention in surface depressions. The delayed infiltration is introduced by the upper zone function.

The infiltration capacity, the maximum rate at which soil will accept infiltration, is a function of fixed characteristics of the watershed, e.g., soil type, permeability, land slopes, and vegetal cover; and of variable characteristics, primarily soil moisture content. Soils containing clay colloids may expand as moisture content increases, thus reducing pore space and infiltration capacity. The actual rate at any time is equal to the infiltration capacity or the supply rate (precipitation minus interception plus surface detention), whichever is less.

Traditionally, infiltration has been represented by an infiltration capacity curve in which the capacity is an exponential function of time. This is in accord with experimental evidence provided the supply rate always exceeds the capacity. Since supply rates are frequently less than infiltration capacity, the variation of infiltration capacity is controlled by accumulation of soil moisture and may not be described by any smooth function of time.

Infiltration relationships used for continuous simulation must:

(1) Represent mean infiltration rates continuously. Since variable moisture supply rates preclude continuous functions of time, expressions for infiltration as a function of soil moisture content are used.

(2) Represent the areal variation in infiltration, i.e., infiltration capacities at any time are distributed about the watershed mean value of infiltration.

To meet the first requirement the LANDS subprogram uses a method based on infiltration equations developed by Philips (82).

$$F = st^{\frac{1}{2}} + at \qquad (31)$$

$$f = \frac{st^{-\frac{1}{2}}}{2} + a \qquad (32)$$

Where F = cumulative infiltration, f = infiltration rate, t = time, a and s = constants that depend on soil properties.

If the constant a is small, Equations 31 and 32 can be written:

$$fF = \frac{s^2}{2} \qquad (33)$$

Since $s^2/2$ is constant, Equation 33 continuously relates infiltration rate to cumulative infiltration or infiltrated volume. This is the type of relationship needed in hydrologic simulation.

Equation 33 will apply approximately to intermittent infiltration when the moisture distribution in the soil profile adjusts between rains. Homogeneous soil is also assumed, but a decrease in permeability as depth increases is more common. Therefore, Equation 33 is modified to:

$$fF^b = \text{constant} \qquad (34)$$

where b = a constant greater than one. Numerous trials have resulted in adoption of b = 2 as a standard value.

The second requirement listed above, representation of areal variations in infiltration capacity, has not normally been considered in applications of the infiltration concepts. Areal variation results from differences in soil type and permeability and from differences in soil moisture, which in turn result from differing vegetal cover, precipitation, and exposure to evaporation. It can be expected that the infiltration capacities that exist from point to point in a watershed at a given time will have some distribution about a mean value (Figure 38). The corresponding cumulative infiltration capacity curve (Figure 39) is of interest as a basis for runoff volume calculations. The solid line sketched in Figure 39 is plotted from the example of an actual frequency distribution sketched in Figure 38.

The shape of the cumulative frequency distribution that will apply in a watershed at any time is impractical to determine, and for mathematical simplification the dashed line in Figure 39, corresponding to the dashed frequency distribution in Figure 38, is assumed in LANDS. The assumption of a linear variation is reasonably well verified by the limited experimental data that is available, and experience indicates that the assumption yields satisfactory results.

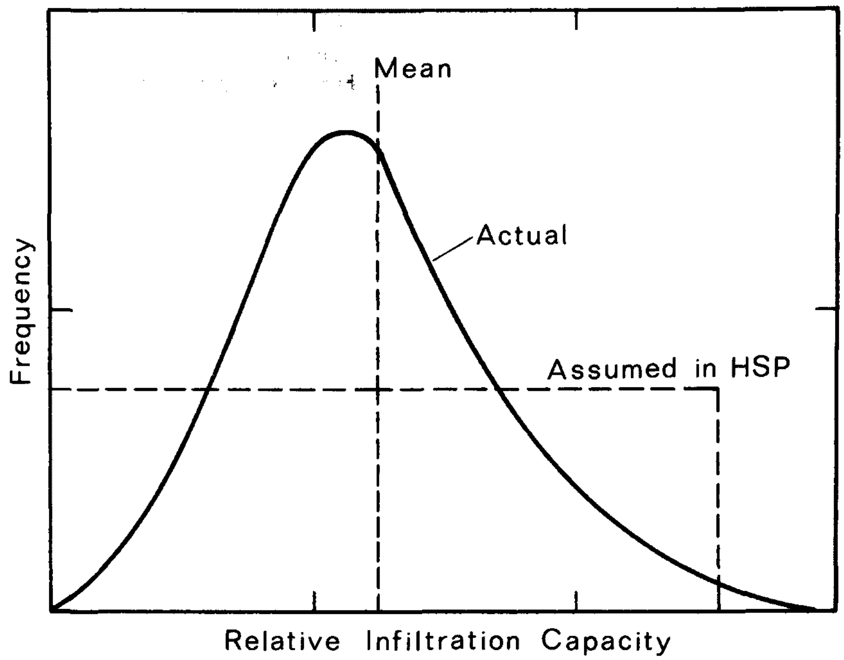

Figure 38. Schematic frequency distribution of infiltration capacity in a watershed

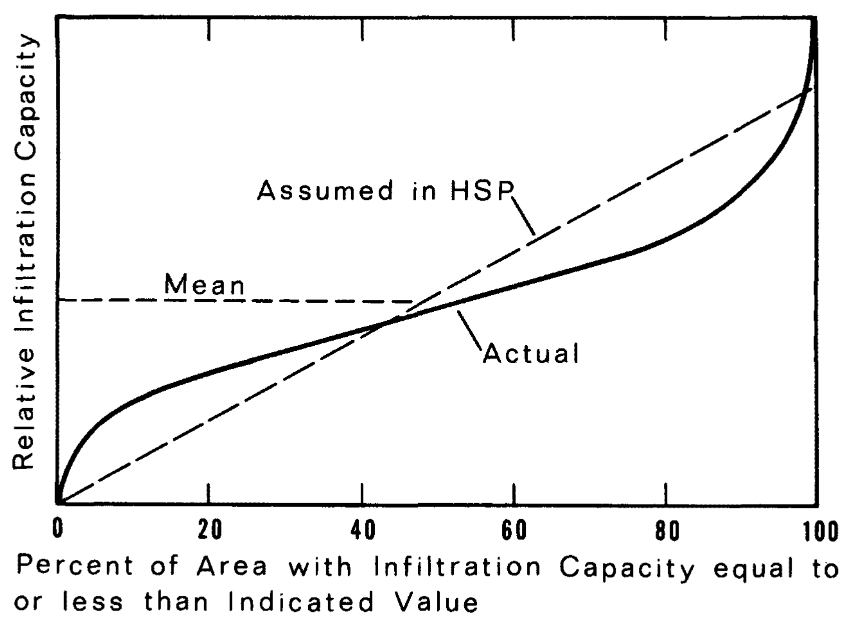

Figure 39. Cumulative frequency distribution of infiltration capacity

The results of the assumptions developed above are illustrated in Figure 40. Rainfall or snowmelt gives a moisture supply of x inches in a certain time interval. The cross hatched area in Figure 40 represents the infiltration that is added to soil moisture or ground water storage in the time interval.

The mean infiltration capacity $\bar{f}$ is time variable, decreasing as infiltration increases the soil moisture content. The value of $\bar{f}$ is calculated based on Equation 34

$$\bar{f} = \mathrm{INFIL}/(\mathrm{LZS}/\mathrm{LZSN})^2 \qquad (35)$$

LZS/LZSN is a dimensionless soil moisture storage ratio, LZS is the current storage in the soil profile, and LZSN (an input parameter) is an index level for moisture storage. INFIL is an input parameter that establishes an index infiltration level, and is equal to $\bar{f}$ when LZS/LZSN = 1. Numeric values of LZSN and INFIL are discussed in the User Manual, Appendix A.

To illustrate the sequence of calculations for time dependence of infiltration consider that rainfall produces the moisture supply x in Figure 40 in a given time interval. Infiltration occurs and the variable soil moisture storage LZS increases. In the next time interval f will decrease since LZS/LZSN in Figure 41 has increased. The combination of functions represented by Figures 40 and 41 simulates the complex time and areal variation of infiltration over a watershed. Simulation algorithms make infiltration a function of the supply rate and vary continuously the area contributing to runoff.

INTERFLOW

Infiltration may lead to interflow, runoff that moves laterally in the soil for some part of its path toward a stream channel. Interflow is encouraged by relatively impermeable soil layers and has been observed to follow roots and animal burrows in the soil. Interflow may come to the surface to join overland flow if its flow path intersects the surface. Figure 40 is extended (Figure 42) to infiltration for the interflow process.

The variable c is defined by

$$c = \mathrm{INTER} * 2^{(\mathrm{LZS}/\mathrm{LZSN})} \qquad (36)$$

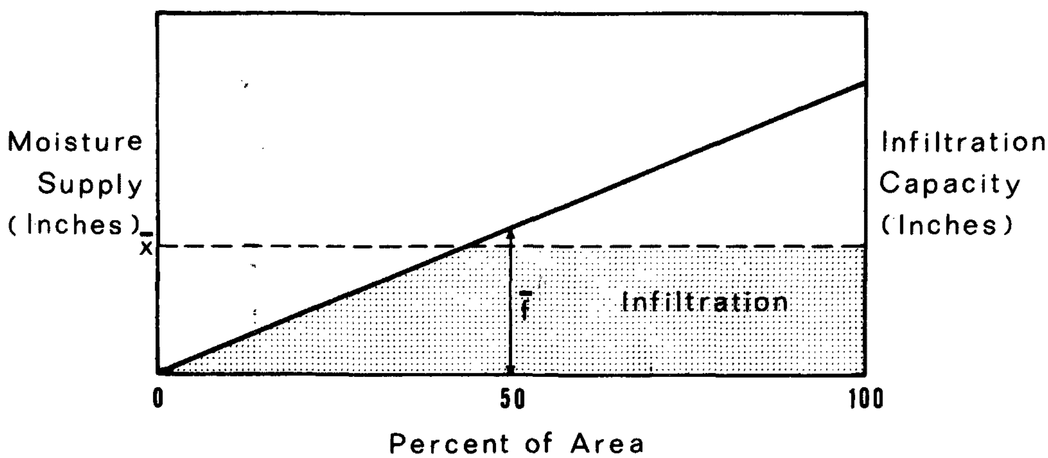

Figure 40. Application of cumulative frequency distribution of infiltration capacity in HSP

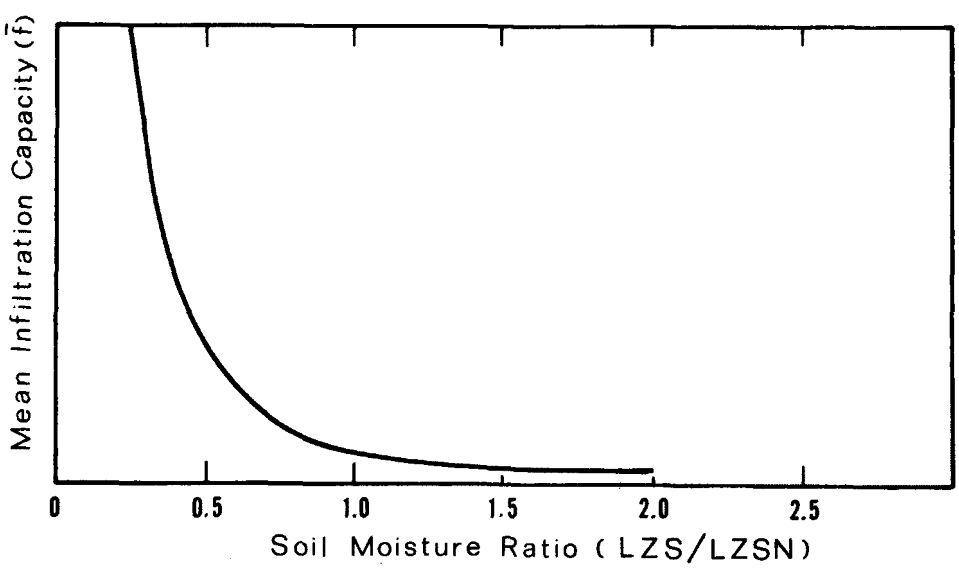

Figure 41. Mean watershed infiltration as a function of soil moisture

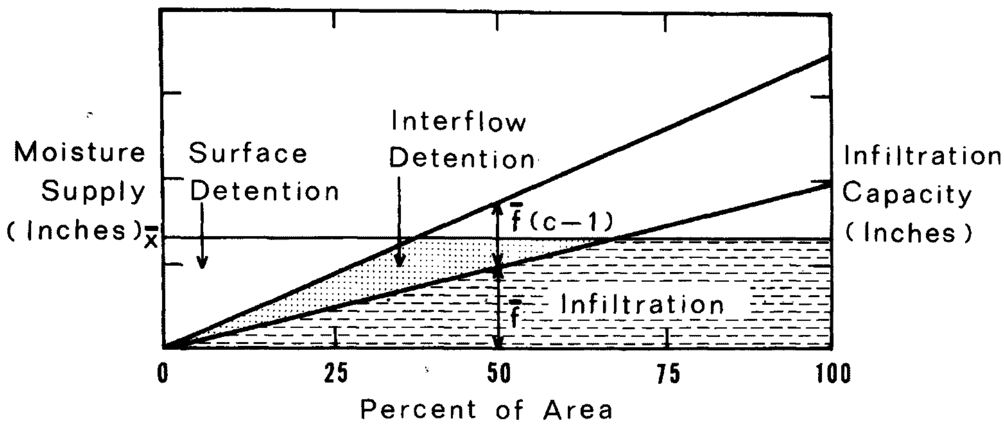

Figure 42. Cumulative frequency distribution of infiltration capacity showing infiltrated volumes, interflow and surface dentention

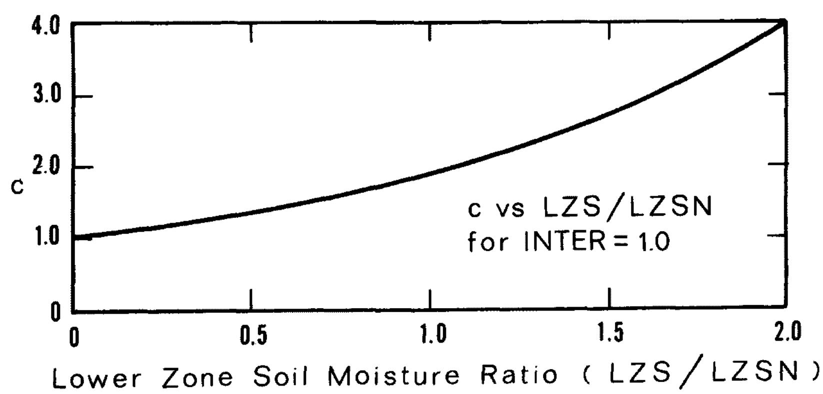

Figure 43. Interflow c as a function of LZS/LZSN

an empirical equation that results in the variation with soil moisture sketched in Figure 43. INTER is an input parameter that governs the volume assigned to interflow.

This simulation scheme makes interflow a function of the local infiltration rate and of soil moisture, i.e., the higher the soil moisture, the greater the fraction of infiltration which becomes interflow. The combination of interflow and infiltration functions yields a smooth response to variations in moisture supply in any time interval. Figure 44 illustrates this response.

UPPER ZONE

Moisture that is not infiltrated directly will increase surface detention storage. The increment to surface detention calculated from Figure 42 will either contribute to overland flow or enter upper zone storage. Depression storage and storage in highly permeable surface soils are modeled by the upper zone. The upper zone inflow percentage P is independent of rainfall intensity, but upper zone storage capacity is low. Moisture is lost from the upper zone by evaporation and percolation to the lower zone and ground water storages.

The following expressions are used to calculate the response of the upper zone storage. The upper zone has a nominal capacity given by the input parameter UZSN. The percentage P of a potential addition to overland flow surface detention that is held in the upper zone is a function of the upper zone storage UZS and the nominal capacity UZSN (Figure 45). When the ratio UZS/UZSN is less than two,

$$P = 100 \left\{ 1.0 - \left(\frac{UZS}{2*UZSN}\right)*\left(\frac{1.0}{1.0 + k_1}\right)^{k_1} \right\} \qquad (37)$$

where $k_1 = 2.0 \left| \left(\frac{UZS}{2*UZSN}\right) - 1.0 \right| + 1.0 \qquad (38)$

When UZS/UZSN is greater than 2.0 the percentage is given by

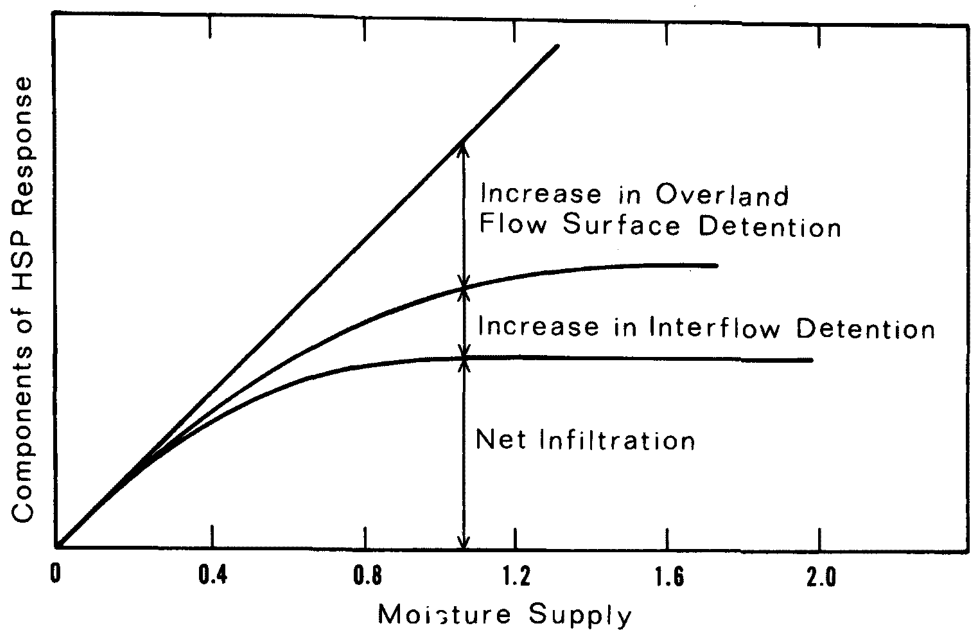

Figure 44. Components of HSP response vs. moisture supply

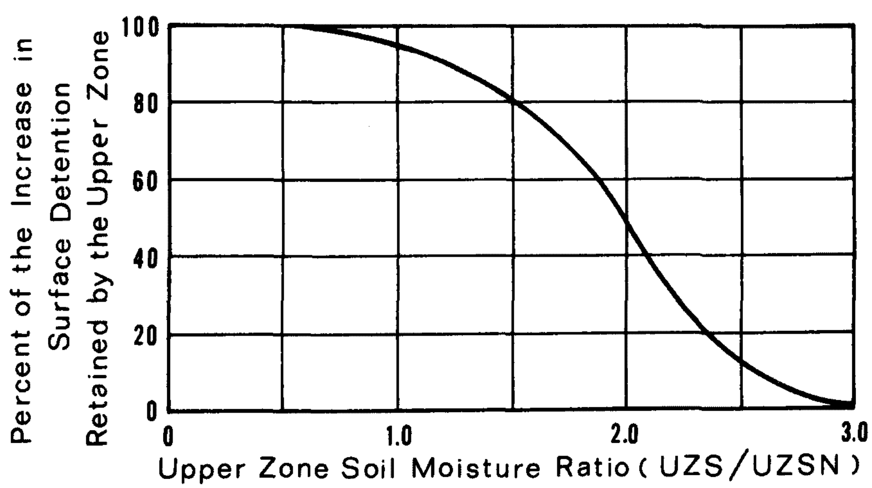

Figure 45. Surface detention retained in the upper zone

$$P = 100 \left(\frac{1.0}{1.0 + k_2}\right)^{k_2} \tag{39}$$

where k_2 is

$$k_2 = 2.0 \left|(UZS/UZSN) - 2.0\right| + 1.0 \tag{40}$$

The upper zone storage prevents overland flow from a portion of the watershed depending on the value of the ratio UZS/UZSN, but since the nominal capacity UZSN is small, the upper zone retention percentage decreases rapidly with increments of accretion of water early in the storm.

Percolation (PERC) occurs from the upper zone to the ground water and lower zone storages when the upper zone storage ratio UZS/UZSN exceeds the lower zone storage ratio LZS/LZSN. This is calculated as

$$PERC = 0.1 * INFIL * UZSN * \left\{(UZS/UZSN) - (LZS/LZSN)\right\}^3 \tag{41}$$

where INFIL is the infiltration level input parameter and PERC is the percolation rate in inches/hour. Evapotranspiration occurs from the upper zone storage at the potential rate if UZS/UZSN is greater than 2.0. If UZS/UZSN is less than 2.0 the portion of the potential evapotranspiration (PET) that is satisfied by upper zone is given by

$$ET\ (actual) = 0.5 * (UZS/UZSN) * PET \tag{42}$$

Potential evapotranspiration that is not assigned to the upper zone is passed to the lower zone. Equation 42 models direct evaporation from near-surface soil. Moisture loss from the lower zone models transpiration by vegetation.

The use of a nominal rather than an absolute capacity for the upper zone storage permits a smooth increase in overland flow rates as upper zone storage increases. If an absolute capacity were used, there would be an abrupt increase in overland flow when the capacity was attained. Such an abrupt change is not consistent with experience nor with the observation that a truly "saturated" state is rarely, if ever, observed. Because of the use of a nominal capacity, it is not possible to define upper zone storage in any rigorous physical sense. It is best viewed as an input parameter representing moisture retention at and near the soil surface.

OVERLAND FLOW

The movement of water in surface or overland flow is an important land surface process. Interactions between overland flow and infiltration need to be considered since both processes occur simultaneously. The variations in rates of infiltration described above allow overland flow in areas with low infiltration while preventing overland flow in other areas. During overland flow, water held in detention storage remains available for infiltration. Surface conditions such as heavy turf or very mild slopes that restrict the velocity of overland flow tend to reduce the total quantity of runoff by allowing more time for infiltration. Short, high intensity rainfall bursts are attenuated by surface detention storage reducing the maximum outflow rate from overland flow.

A wide range of methods for the calculation of unsteady overland flow was considered. The only rigorous general methods for simulating unsteady overland flow are finite difference techniques for the numerical solution of the partial differential equations of continuity and momentum. These methods have a major disadvantage for continuous simulation since substantial amounts of computer time are needed. In a natural watershed there are areal variations in the amount of runoff moving in overland flow because of areal variations in infiltration. Average values must be used in the calculations for the length, slope, and roughness of overland flow. Hence, the accuracy gained by using finite difference methods for overland flow is subject to question because of the limitations on the input data.

In LANDS, overland flow is treated as a turbulent flow process. Since continuous surface detention storage is computed, the volume of surface detention was chosen as the parameter to be related to overland flow discharge. Using the Chezy-Manning equation, the relationship between surface detention storage at equilibrium D_e, the supply rate to overland flow i, Manning's n and the length L and slope S of the flow plane is

$$D_e = \frac{0.000818\, i^{0.6}\, n^{0.6}\, L^{1.6}}{S^{0.3}} \qquad (43)$$

Using the ratio of detention depth at any instant D to detention depth at equilibrium D_e as an index of the distribution of flow over the overland plane, an empirical expression relating outflow depth and detention storage which fits experimental data quite well is

$$y = \frac{D}{L} * \left[1.0 + 0.6*\left(\frac{D}{D_e}\right)^3\right] \qquad (44)$$

Substituting Equation 44 in the Chezy-Manning Equation the rate of discharge from overland flow in $ft^3/sec/ft$ is

$$q = \frac{1.486}{n} * S^{1/2} * \left(\frac{D}{L}\right)^{5/3} * \left[1.0 + 0.6*\left(\frac{D}{D_e}\right)^3\right]^{5/3} \qquad (45)$$

where D_e is a function of the current supply rate to overland flow and is calculated from Equation 46. During recession flow when D_e is less than D the ratio D/D_e is assumed to be one. LANDS continuously solves a continuity equation

$$D_2 = D_1 + \Delta D - \bar{q}\,\Delta t \qquad (46)$$

where Δt is the time interval used, D_2 is the surface detention at the end of the current time interval, D_1 is the surface detention at the end of the previous time interval, ΔD is the increment added to surface detention in the time interval, and $\bar{q}$ is the overland flow into the stream channel during the time interval. The discharge $\bar{q}$ is a function of the moisture supply rate and of $(D_1 + D_2)/2$, the average detention storage during the time interval (D in Equation 45).

The system of equations can be solved numerically with good accuracy if the time interval of the calculation is sufficiently small so that the value of discharge in any time interval remains a small fraction of the volume of surface detention. In the NPS Model calculations of discharge from overland flow are made on a 15-minute time interval.

The overland flow calculations enter the delayed infiltration process through the fact that any water remaining in detention at the end of an interval is added to the rainfall minus interception of the next period to give the supply rate for the infiltration calculations. Overland flow detention is an important part of the total delay time in runoff on small watersheds. Figures 46 and 47 illustrate the "fit" of the LANDS simulation of overland flow to experimental data. Figure 48 shows that on a watershed

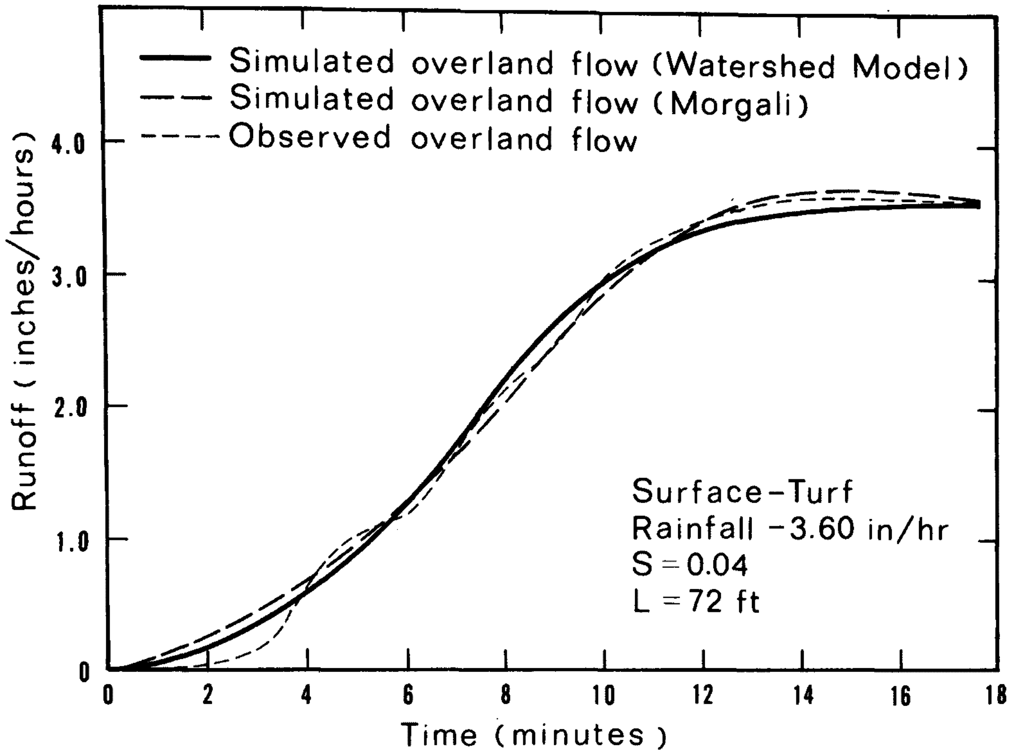

Figure 46. HSP overland flow simulation

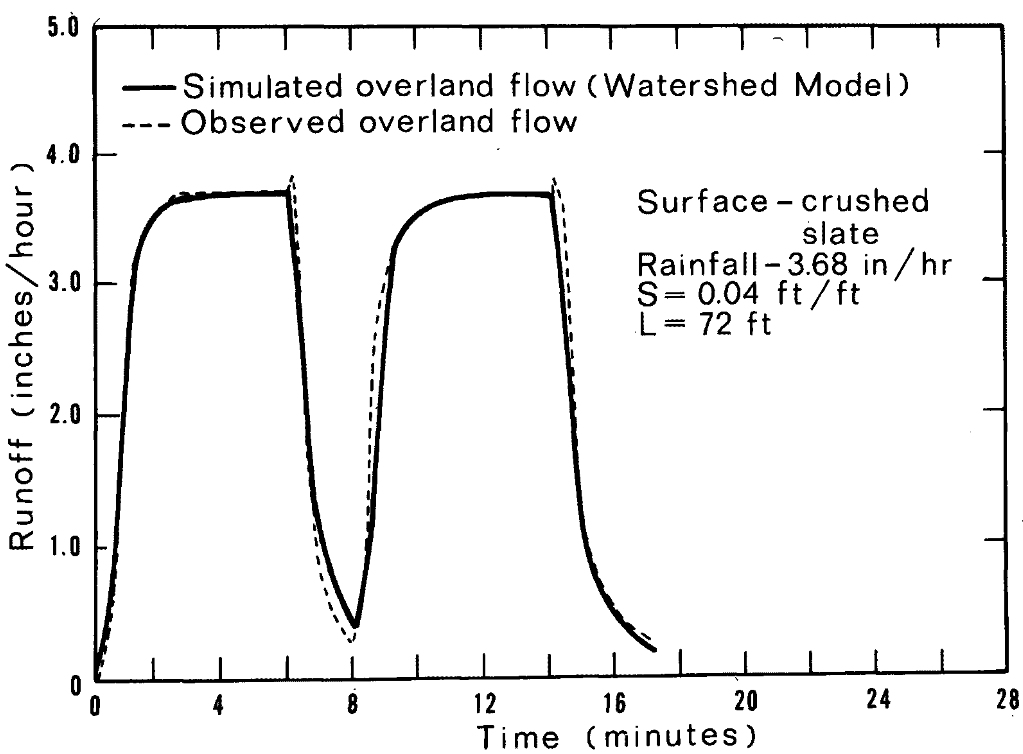

Figure 47. HSP overland flow simulation

of 0.26 square miles, overland flow simulation closely approximates the actual outflow hydrograph indicating that overland flow delay is much more important than channel storage in controlling hydrograph shape. Figure 49 shows a similar comparison for a watershed of 18.5 square miles which is partly urbanized. Here, the overland flow effects on hydrograph shape are relatively small although the effect through delayed infiltration is still present.

INTERFLOW

The calculation of an increment to interflow detention storage SRGX was described above. Outflow from this storage to the stream is calculated on a 15-minute time interval by the equation

$$\text{INTF} = \text{LIRC4} * \text{SRGX} \qquad (47)$$

where

$$\text{LIRC4} = 1.0 - (\text{IRC})^{1/96} \qquad (48)$$

IRC, an input parameter, is the daily recession constant for the interflow component calculated as the ratio of the interflow discharge at any instant to the interflow discharge 24 hours earlier.

LOWER ZONE AND GROUND WATER STORAGE FUNCTION

This function operates on the direct or immediate infiltration (Figure 42) and the percolation from upper zone storage (PERC in Equation 41). The available water is divided between the lower zone soil moisture storage and the ground water storage. The division is based on the lower zone storage ratio LZS/LZSN where LZSN is the lower zone nominal capacity. The percentage of the infiltration plus percolation that enters ground water storage (Figure 50) is given by

$$P_g = 100*\frac{\text{LZS}}{\text{LZSN}}*\left(\frac{1.0}{1.0 + z}\right)^z \qquad (49)$$

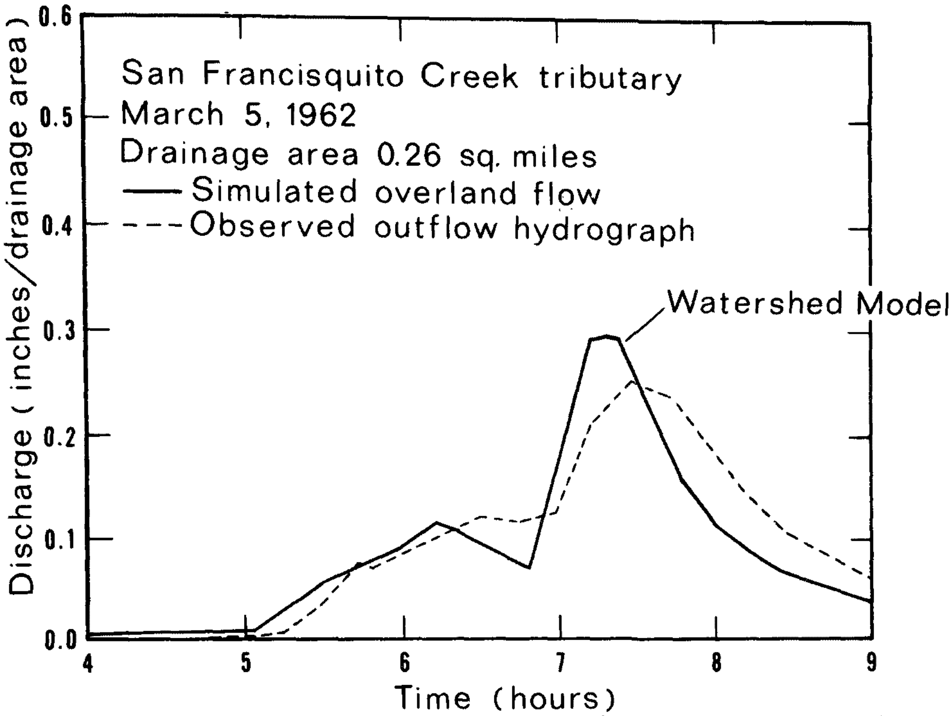

Figure 48. Hydrograph simulation (0.26 square miles)

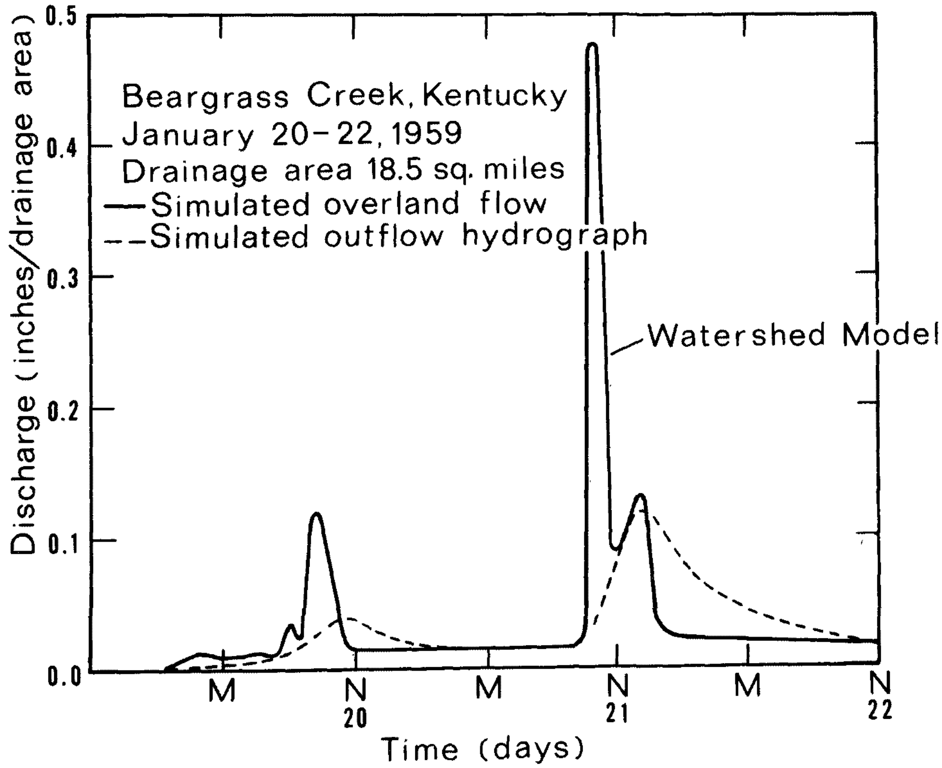

Figure 49. Hydrograph simulation (18.5 square miles)

when LZS/LZSN is less than 1.0 and by

$$P_g = 100* \left\{1.0 - \left(\frac{1.0}{1.0 + z}\right)^z\right\} \quad (50)$$

when LZS/LZSN is greater than 1.0, z is defined by

$$z = 1.5* \left|\frac{LZS}{LZSN} - 1.0\right| + 1.0 \quad (51)$$

These relationships are plotted in Figure 50.

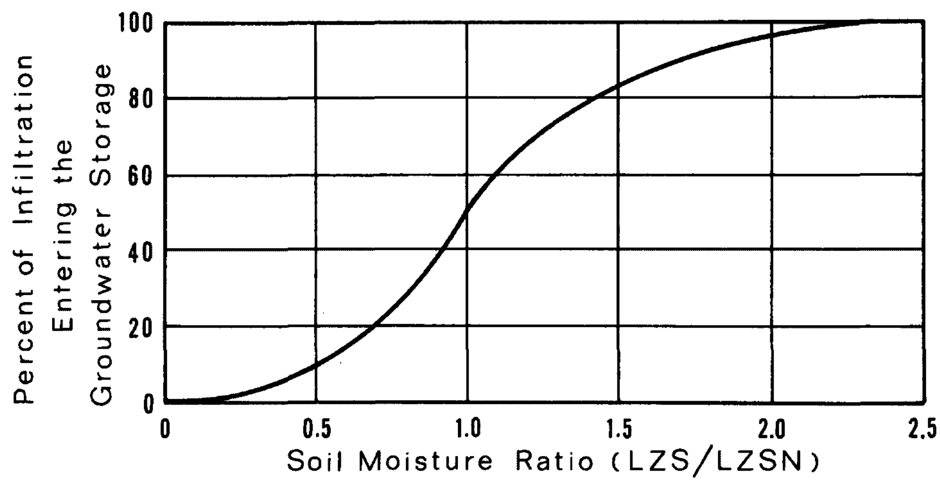

Figure 50. Infiltration entering groundwater storage

LOWER ZONE STORAGE

The lower zone storage is the main moisture storage for the land surface. Like the upper zone storage, it is defined in terms of a nominal capacity LZSN, the storage level at which half of the incoming infiltration enters the lower zone and half moves to ground water. This use of a nominal rather than an absolute capacity serves the same purpose as for the upper zone, i.e., it avoids the abrupt change which would occur if an absolute capacity were reached and permits a smooth transition in hydrologic performance as the lower zone storage increases.

Physically the lower zone may be viewed as the entire soil from just below the surface down to the capillary fringe above the water table. In practice we are concerned only with the transient portion of this storage, i.e., the volume which is emptied by evapotranspiration and refilled by infiltration. Consequently, numerical values of the input parameter LZSN do not necessarily reflect the total moisture storage capacity of the lower zone.

GROUND WATER

Equations 49 and 50 determine the accretion to ground water in each time increment. If some part of this water is believed to percolate to deep ground water storage, this is modeled by allowing a fixed percentage of the inflow to ground water to bypass the active ground water storage and proceed directly to the deep or inactive storage. This portion is assigned by the input parameter K24L. Water assigned to deep ground water is lost from the surface phase of the hydrologic cycle of the watershed. It may leave the basin as subsurface flow, but it does not contribute to streamflow.

The outflow from active ground water storage at any time is based on the simplified model in Figure 51. The discharge of an aquifer is proportional to the product of the cross sectional area and the energy gradient of the flow. A representative cross sectional area of flow is assumed proportional to the ground water storage level computed by LANDS.

Groundwater outflow (GWF) is calculated on 15-minute intervals as a function of ground water storage (SGW) as follows:

$$GWF = LKK4 * SGW \quad (52)$$

where

$$LKK4 = 1.0 - (KK24)^{1/96} \quad (53)$$

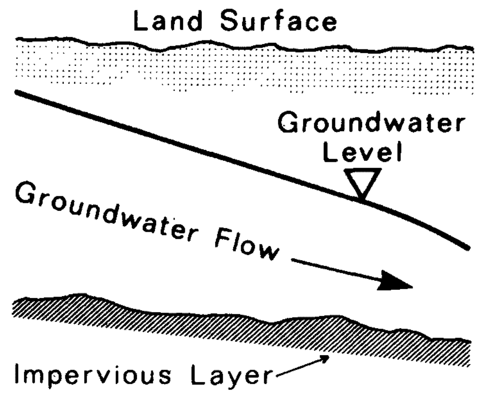

Figure 51. Groundwater flow

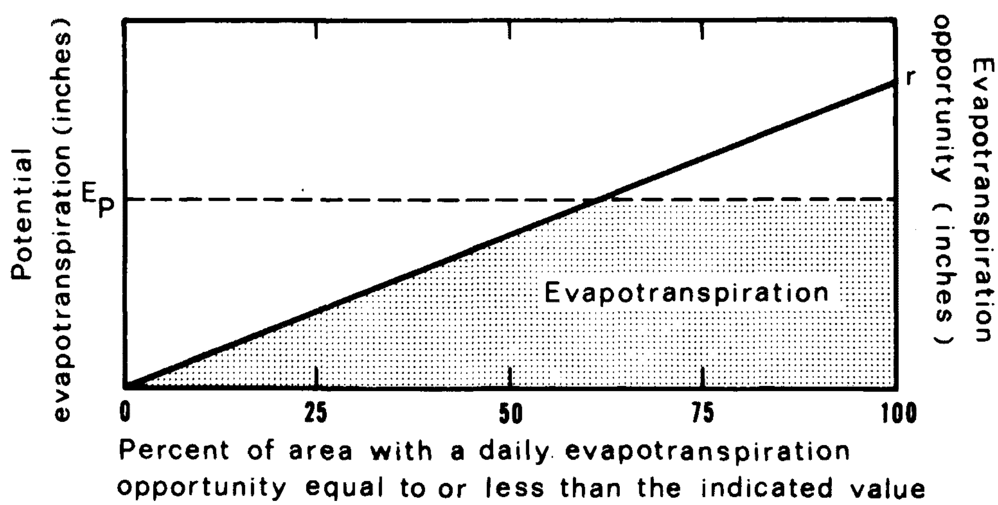

Figure 52. Potential and actual evapotranspiration

KK24 is the minumum observed daily recession constant of ground water flow, the ratio of current ground water discharge to the ground water discharge twenty-four hours earlier. Equation 52 reproduces the commonly used logarithmic depletion curve, i.e., the flow after a period of n days decreases by $(KK24)^n$, and a semi-logarithmic plot of discharge vs. time is a straight line.

EVAPOTRANSPIRATION

The volume of water that leaves a watershed as evaporation and transpiration exceeds the total volume of streamflow in most hydrologic regimes. Continuous estimates of actual evapotranspiration must therefore be made by LANDS. There are two components involved in estimating actual evapotranspiration. Measured potential evapotranspiration and calculated soil moisture conditions are used to estimate actual evapotranspiration.

Potential evapotranspiration is assumed to be equal to lake evaporation estimated from Weather Bureau Class A pan records (74). This procedure is more convenient than an approach based on meteorological data since input requirements are less stringent. A single variable, adjusted pan evaporation data, serves a purpose that would otherwise require input of several variables. If pan evaporation data are not available, the input data for potential evapotranspiration may be estimated by any appropriate method.

The relationship of actual evapotranspiration to potential evapotranspiration over large areas should logically be a function of moisture conditions. Even if transpiration from vegetation is independent of soil moisture until the wilting point is reached, variable soil moisture will cause wilting in some parts of a watershed but not in others. Evaporation from soil, a component of the total process, is dependent on moisture conditions.

When near surface storage is depleted, the concept of evapotranspiration opportunity is defined as the maximum quantity of water accessible for evapotranspiration in a time interval at a point in the watershed. It is analogous to infiltration capacity and would have a cumulative distribution similar to that in Figure 39. The cumulative evapotranspiration opportunity curve will be a function of watershed soil moisture conditions. This curve estimates actual evapotranspiration for any quantity of potential evapotranspiration just as the cumulative infiltration capacity curve estimates net infiltration for any moisture supply.

Evapotranspiration occurs from interception storage at the potential rate. Evapotranspiration opportunity controls evapotranspiration from the lower zone storage. Daily lake evaporation, daily potential evapotranspiration data, or average daily rates for semi-monthly periods are used as input. LANDS computes hourly values from the daily totals using an empirical diurnal variation.

Potential evapotranspiration will result in a water loss or actual evapotranspiration only if water is available. LANDS first attempts to satisfy the potential from interception storage and from the upper zone in that order. The contribution to actual evapotranspiration of the upper zone is limited if UZS/UZSN is less than 2.0 (Equation 42). Any remaining potential enters as E_p in Figure 52. Since evapotranspiration opportunity in a watershed on a given day may be expected to vary through a considerable range, a cumulative frequency distribution similar to those found for infiltration capacity in Figure 40 might be reasonable.

Following the assumption made for infiltration capacity the cumulative frequency distribution of evapotranspiration opportunity is assumed to be linear (Figure 52). The quantity of water lost by evapotranspiration from the lower zone when E_p is less than r is given by the cross-hatched trapezoid of Figure 52. The variable r is an index given by

$$r = \left(\frac{0.25}{1.0 - K3}\right)*\left(\frac{LZS}{LZSN}\right) \qquad (54)$$

Evapotranspiration is further limited when K3 is less than 0.5. A fraction of the watershed area given by 1.0-2*K3 is considered devoid of vegetation that can draw from the lower zone storage. K3 is an input parameter that is an index to vegetation density.

APPENDIX C

SNOWMELT SIMULATION ALGORITHMS

As stated in Section VI, the objective of snow accumulation and melt simulation is to approximate the physical processes (and their interactions) in order to evaluate the timing and volume of melt water released from the snowpack. The algorithms used in the NPS Model are based on extensive work by the Corps of Engineers (37), Anderson and Crawford (38), and Anderson (39). In addition, empirical relationships are employed when quantitative descriptions of the process are not available. The algorithms presented below are identical to those employed in HSP (23) and the ARM Model (21). The flowchart of the snowmelt routine was shown in Figure 4 of this report. The major simulated processes can be divided into the two general categories of melt components and snowpack characteristics. The algorithms for the individual processes within each of these categories are briefly presented below in computer format and English units to promote recognition of the equations in the Model source code. Refer to the original source materials for a more in-depth explanation.

MELT COMPONENTS

Radiation Melt

The total melt component in each hour due to incident radiation energy is calculated as

$$RM = (RA + LW)/203.2 \qquad (55)$$

where RM = radiation melt, in./hr
RA = net solar radiation, langleys/hr

LW = net terrestrial radiation, langleys/hr
203.2 = langleys required to produce 1 inch of melt from snow at 32 °F

The effects of solar and terrestrial radiation are evaluated separately. An input parameter, RADCON, allows the user to adjust the solar radiation melt component to the conditions of the particular watershed. Daily solar radiation is required input data for the present version of the snowmelt routine. Hourly values are derived from a fixed 24-hour distribution and are modified by the watershed forest cover (input parameter F) and the effective albedo (calculations described under 'snowpack characteristics').

Terrestrial radiation is not generally measured; hence, an estimate must be obtained from theoretical considerations and modified by environmental factors (e.g., cloud cover, forest canopy, etc.). The following relationship for terrestrial radiation based on Stefan's Law of Black Body Radiation (37).

$$R = \sigma TA^4\{F + (1-F)0.757\} - \sigma TS^4 \qquad (56)$$

where R = net terrestrial radiation, langleys/min
F = fraction forest cover
TA = air temperature, °K
TS = snow temperature, °K
σ = Stefan's constant, 0.826×10^{-10}, langleys/min/°K

The snowmelt routine employs a linear approximation to the above relationship and modifies the resulting hourly terrestrial radiation for cloud cover effects. Back radiation from clouds can partially offset terrestrial radiation losses from the snowpack. Since cloud cover data information is not generally available and transposition of data from the closest observation point can be highly inaccurate, a daily cloud cover correction factor is estimated to reduce this radiation loss from the pack. For days when precipitation occurs, terrestrial radiation loss from the pack is reduced by 85 percent to account for the effects of complete cloud cover; this reduction factor decreases to zero in the days following the storm event.

Condensation-Convection Melt

The melt resulting from the heat exchange due to condensation and convection is often combined in a single equation. A constant ratio between the coefficients of convection and condensation (Bowen's ratio) is generally assumed. Since the two mechanisms are operative under different climatic situations, the algorithms are presented here separately. Condensation only occurs when the vapor pressure of the air is greater than saturation, whereas convection melt only occurs when the air temperature is greater than freezing. The algorithms are

CONV = CCFAC*.00026*WIN*(TX-32)*(1.0-0.3*(MELEV/10000)) (57)

CONDS = CCFAC*.00026*WIN*8.59*(VAPP-6.108) (58)

where
CONV = convection melt, in./hr
CONDS = condensation melt, in./hr
CCFAC = input correction factor to adjust melt values to field conditions
WIN = wind movement, mi/hr
TX = air temperature, $^{\circ}F$
MELEV = mean elevation of the watershed, ft
Note: the expression 1.0-0.3*(MELEV/10000) is a linear approximation of the relative change in air pressure with elevation, and corresponds to P/P_0 in "Snow Hydrology" (37).
VAPP = vapor pressure of the air, millibars
6.108 = saturation vapor pressure over ice at 32 $^{\circ}F$, millibars
0.00026,
8.59 = constants in the analogous expression in "Snow Hydrology" (Note: 0.00026 corresponds to the daily coefficient, 0.00629, adjusted to an hourly basis.)

Rain Melt

Whenever rain occurs on a snowpack, heat is transmitted to the snowpack, and melt is likely to occur. The quantity of snowmelt from this component is calculated as follows, assuming the temperature of the rain equals air temperature:

RAINM = ((TX-32)*PX)/144 (59)

where
RAINM = rain melt, in./hr
PX = rain, in./hr
TX = air temperature, $^{\circ}F$
144 = units conversion factor, $^{\circ}F$

Ground Melt

As mentioned previously, melt due to heat supplied from the land surface and subsurface can be significant in the overall water balance. Since this component is relatively constant, an input parameter specifies the daily contribution from this component. Heat loss from the snowpack can result in snowpack temperatures less than 32 °F. When this occurs, the groundmelt component is reduced 3 percent for each degree below 32 °F.

SNOWPACK CHARACTERISTICS

Rain/Snow Determination

The form of precipitation is critical to the reliable simulation of runoff and snowmelt. The following empirical expression based on work by Anderson (39) is employed to calculate the effective air temperature below which snow occurs:

$$SNTEMP = TSNOW + (TX-DEWX)*(0.12 + 0.008*TX) \qquad (60)$$

where SNTEMP = temperature below which snow occurs, °F
TSNOW = input parameter, °F
TX = air temperature, °F
DEWX = dewpoint temperature, °F

Variable meteorologic conditions and the relatively imprecise estimates of hourly temperature derived from maximum and minimum daily values can cause some discrepancies in this determination. For this reason, the use of TSNOW as an input parameter allows the user flexibility in specifying the form of precipitation recorded in meteorologic observations. The above expression allows snow to occur at air temperatures above TSNOW if the dewpoint temperature is sufficiently depressed. However, a maximum variation of one Fahrenheit degree is specified resulting in a maximum value for SNTEMP = TSNOW + 1.

Snow Density and Compaction

The variation of the density of new snow with air temperature is obtained from "Snow Hydrology" (37) in the following form:

$$DNS = IDNS + (TX/100)^2 \qquad (61)$$

where DNS = density of new snow
IDNS = density of new snow at an air temperature of 0 °F
TX = air temperature, °F

Snow density is expressed in inches of water equivalent for each inch of snow. With snow fall and melt processes occurring continuously, the snow density is evaluated each hour. If the snow density is less than 0.55, compaction of the pack is assumed to occur. The new value for snow depth is calculated by the empirical expression:

DEPTH2 = DEPTH1*(1.0-0.00002*(DEPTH1*(.55-SDEN))) (62)

where DEPTH2 = new snow depth, in.
DEPTH1 = old snow depth, in.
SDEN = snow density

Areal Snow Coverage

The areal snow coverage of a watershed is highly variable. Watershed response differs depending on whether the precipitation, especially in the form of rain, is falling on bare ground or snow covered land. The areal snow coverage is modeled in the snowmelt routine by specifying that the water equivalent of the existing snowpack, PACK, must exceed the variable IPACK for complete coverage. IPACK is initially set to a low value to insure complete coverage for the initial events of the season and is reset to the maximum value of PACK attained to date in each snowmelt season. Since the ratio PACK/IPACK indicates the fraction of the watershed with snow coverage, less than complete coverage results as the melt process reduces the value of PACK. An input parameter, MPACK, allows the user to specify the water equivalent required for complete snow coverage. Thus MPACK is the maximum value of IPACK, resulting in complete coverage when PACK is greater than MPACK, and less than complete coverage (PACK/MPACK) when PACK decreases to values less than MPACK.

Albedo

The albedo or reflectivity of the snowpack is a function of the condition of the snow surface and the time since the last snow event. During the snow season, the maximum and minimum values for albedo are specified as 0.85 and 0.60, respectively. It is reset to approximately the maximum value with each major snow event and decreases gradually as the snowpack ages.

Snow Evaporation

Evaporation from the snow surface is usually quite small, but its inclusion in snowmelt calculations is necessary to complete the overall water balance of the snowpack. The physical process is the opposite of condensation occurring only when the vapor pressure of the air is less than the saturation vapor pressure over snow. The following empirical relationship is used to calculate hourly snow evaporation:

SEVAP = EVAPSN*0.0002*WIN*(VAPP-SATVAP)*PACKRA (63)

where SEVAP = snow evaporation, in./hr
EVAPSN = correction factor to adjust to field conditions
WIN = wind movement, mi/hr
VAPP = vapor pressure of the air, millibars
SATVAP = saturation vapor pressure over snow, millibars
PACKRA = fraction of watershed covered with snow

Snowpack Heat Loss

Heat loss from the snowpack can occur if terrestrial back radiation from the pack is large, or if air temperatures are very low. Since this heat is emitted by the pack, it is simulated as a negative heat storage, NEGMLT, which must be satisfied before melt can occur. Any heat available to the snowpack first offsets NEGMLT before melting can occur. The hourly increment to NEGMLT is calculated from the following empirical relationship whenever the air temperature is less than the temperature of the pack:

GM = 0.0007*(TP-TX) (64)

where GM = hourly increment to negative heat storage, in.
TP = temperature of the pack, $^{\circ}$F
TX = air temperature, $^{\circ}$F

NEGMLT and GM are calculated in terms of inches of melt corresponding to the heat loss from the pack. The current value of NEGMLT is used to calculate the temperature of the pack simulating the drop in temperature as heat loss from the pack continues. A maximum value of NEGMLT is calculated as a function of air temperature and the water equivalent of the pack by assuming that the temperature in the pack varies linearly from ambient air temperature at the snow surface to 32 $^{\circ}$F at the soil surface. This maximum negative heat storage is calculated as follows:

$$NEGMM = 0.00695*(PACK/2.0)*(32.0-TX) \quad (65)$$

where NEGMM = maximum negative heat storage, in.
PACK = water equivalent of the snowpack, in.
TX = air temperature, °F (<32 F)
0.00695 = conversion factor, $°F^{-1}$

Snowpack Liquid Water Storage

Liquid water storage within the snowpack is limited by a user input parameter, WC, which specifies the maximum allowable water content per inch of snowpack water equivalent. Thus, the maximum liquid water storage is calculated as WC x PACK. However, this value is reduced if high snow density values are attained.

APPENDIX D

NPS MODEL SAMPLE INPUT LISTING

```
//YJL7412 JOB (A12$X2,510,1,90),'J7412LITWIN'
/*JOBPARM COPIES=2
//JOBLIB DD DSNAME=WYL.X2.A12.YJL.J7412.N01,DISP=(OLD,KEEP),
//        UNIT=DISK,VOL=SER=PUB003
//STEP1 EXEC PGM=NPS
//SYSPRINT DD SYSOUT=A
//FT06F001 DD SYSOUT=A
//FT05F001 DD *
NPS MODEL
SAMPLE INPUT SEQUENCE-HOURLY INPUT PRECIPITATION
 &ROPT  HYCAL=3,  HYMIN=10.0 ,NLAND=4, NQUAL=2, SNOW=1                     &END
 &DTYP  UNIT=-1, PINT=1, MNVAR=0                                           &END
 &STRT  BGNDAY=15, BGNMON=11, BGNYR=1970                                   &END
 &ENDD  ENDDAY=31,  ENDMON=3, ENDYR=1971                                   &END
 &LND1  UZSN=0.40,LZSN=6.0,INFIL=0.04,INTER=2.0,IRC=0.5,AREA=1069.         &END
 &LND2  NN=0.30, L=300., SS=0.10, NNI=0.15, LI=600., SSI=0.10              &END
 &LND3  K1=1.4, PETMUL=1.0, K3=0.25, EPXM=0.15, K24L=0.0, KK24=0.99        &END
 &LND4  UZS=0.000, LZS=2.250, SGW=1.00                                     &END
 &SNO1  RADCON=.25, CCFAC=.25, EVAPSN=0.6                                  &END
 &SNO2  MELEV=800.00,ELDIF=0.0,TSNOW=33.0                                  &END
 &SNO3  MPACK=0.1, DGM=0.0010, WC=0.05, IDNS=0.1                           &END
 &SNO4  SCF=1.10, WMUL=1.0, RMUL=1.0, F=0.5, KUGI=8.0                      &END
 &SNO5  PACK=0., DEPTH=0.                                                  &END
 &WASH  JRER=2.2,KRER=1.50,JSER=1.8,KSER=0.30,JEIM=1.8,KEIM=0.30,TCF=12*1.0 &END
   BOD        GM/L
   SS         GM/L
 OPEN AREA
 &WSCH ARFRAC=0.10, IMPKO=0.05, COVVEC=12*0.90                             &END
 &YPTM PMPVEC=4.,71.,3*0.0,      PMIVEC=4.0,71.,3*0.0                      &END
 &YACR ACUP=30.,     ACUI=30.                                              &END
 &YRMR REPER=0.05,   REIMP=0.08                                            &END
 &INAC  SRERI=1758.,    TSI=106.                                           &END
RESID.AREA
 &WSCH ARFRAC=0.60, IMPKO=0.18, COVVEC=12*0.95                             &END
 &YPTM PMPVEC=4.,71.,3*0.0,      PMIVEC=4.0,71.,3*0.0                      &END
 &YACR ACUP=70.,     ACUI=70.                                              &END
 &YRMR REPER=0.05,   REIMP=0.08                                            &END
 &INAC  SRERI=1880.,    TSI=248.                                           &END
COMMERCIAL
 &WSCH ARFRAC=0.17, IMPKO=0.55, COVVEC=12*0.90                             &END
 &YPTM PMPVEC=4.,71.,3*0.0,      PMIVEC=4.0,71.,3*0.0                      &END
 &YACR ACUP=75.,     ACUI=75.                                              &END
 &YRMR REPER=0.05,   REIMP=0.08                                            &END
 &INAC  SRERI=2658.,    TSI=266.                                           &END
INDUSTRIAL
 &WSCH ARFRAC=0.13, IMPKO=0.75, COVVEC=12*0.90                             &END
 &YPTM PMPVEC=4.,71.,3*0.0,      PMIVEC=4.0,71.,3*0.0                      &END
 &YACR ACUP=80.,     ACUI=80.                                              &END
 &YRMR REPER=0.05,   REIMP=0.08                                            &END
 &INAC  SRERI=2758.,    TSI=284.                                           &END
 EVAP70      4    32    14    27    80    40   165   213    87    71    24    31
 EVAP70      1    24     7   129   103    77   210   187   113   105    13    35
 EVAP70      1    10     6    61   179   215   210   212    72    85     7    21
 EVAP70      3    13    65   126   205   154    91    94   127    81    34    22
 EVAP70      3    25    59    86   169   179   231   144   141   101    51    29
```

56.	EVAP70	4	24	73	40	171	197	197	170	16	70	26	15
57.	EVAP70	4	6	57	119	195	222	209	128	141	85	27	24
58.	EVAP70	4	3	20	148	207	241	155	110	157	16	4	25
59.	EVAP70	10	34	37	176	132	229	111	184	125	25	7	15
60.	EVAP70	4	25	41	129	211	209	221	167	143	72	34	9
61.	EVAP70	4	13	54	113	27	231	223	163	137	51	10	7
62.	EVAP70	10	9	69	87	97	153	221	153	28	26	4	5
63.	EVAP70	2	14	30	21	26	88	145	175	11	19	16	12
64.	EVAP70	8	11	76	138	6	113	161	192	2	73	24	6
65.	EVAP70	12	22	66	114	15	79	120	148	33	56	34	0
66.	EVAP70	3	20	69	153	70	181	232	206	102	55	32	1
67.	EVAP70	4	22	71	154	195	157	239	144	10	73	31	2
68.	EVAP70	5	8	86	26	222	171	47	37	114	75	9	1
69.	EVAP70	3	29	40	16	188	221	31	109	115	59	7	0
70.	EVAP70	8	33	24	34	214	21	200	189	84	17	8	8
71.	EVAP70	6	43	98	40	230	198	199	165	39	20	12	3
72.	EVAP70	1	65	69	88	150	218	204	94	30	11	31	6
73.	EVAP70	10	52	65	178	27	239	201	140	11	19	22	7
74.	EVAP70	12	65	83	175	129	197	154	170	22	33	23	0
75.	EVAP70	3	52	28	167	165	168	172	142	98	18	42	10
76.	EVAP70	8	32	78	171	207	49	193	192	57	39	12	7
77.	EVAP70	16	28	58	208	29	175	132	161	82	21	9	3
78.	EVAP70	2	25	78	117	155	172	129	108	86	8	27	7
79.	EVAP70	24		80	130	99	251	94	81	91	38	6	1
80.	EVAP70	20		88	50	55	248	232	131	88	19	16	5
81.	EVAP70	34		60		109		188	90		25		5

82.	TEMP70	26	8	43	23	35	27	42	26	68	39	73	57	89	70	81	58	73	40	67	36	45	36	62	39
83.	TEMP70	20	5	37	-11	36	31	50	27	53	34	65	50	90	65	87	55	88	54	68	47	43	37	49	29
84.	TEMP70	16	-1	-6	-15	47	36	46	28	74	36	67	41	81	58	76	53	80	64	54	36	43	36	56	34
85.	TEMP70	22	-7	29	-7	46	25	50	25	67	41	74	39	69	51	71	52	83	58	64	30	50	33	35	27
86.	TEMP70	5	-12	32	3	45	21	54	26	60	33	78	50	80	43	81	49	86	53	76	49	56	33	36	9
87.	TEMP70	2	-15	39	13	44	31	50	25	58	25	80	46	81	46	82	52	73	62	72	59	55	31	25	5
88.	TEMP70	3	-11	35	32	45	22	66	21	81	34	85	53	85	65	82	50	86	65	77	58	50	27	33	19
89.	TEMP70	-2	-12	34	22	24	18	70	42	84	53	82	60	76	60	80	58	78	57	63	61	47	28	46	27
90.	TEMP70	13	-4	29	19	30	7	60	33	81	57	83	62	78	54	84	57	80	52	67	39	54	47	41	22
91.	TEMP70	16	-13	33	22	32	16	55	19	76	56	85	63	87	52	85	59	66	44	52	36	55	36	32	17
92.	TEMP70	22	16	30	14	38	12	51	32	59	47	85	66	89	56	85	56	72	43	57	33	48	35	35	30
93.	TEMP70	24	0	18	4	41	15	51	33	78	46	85	64	90	61	86	52	64	48	60	46	45	38	31	26
94.	TEMP70	14	-7	11	-11	28	16	43	35	54	43	74	60	90	67	85	59	50	45	63	50	41	33	29	22
95.	TEMP70	23	6	12	-9	35	16	62	31	50	43	82	57	88	69	89	63	52	45	54	37	33	28	22	-10
96.	TEMP70	28	22	25	4	32	9	68	30	54	45	76	60	77	60	87	66	68	50	49	27	34	24	36	-12
97.	TEMP70	32	9	27	-5	44	10	71	48	56	40	84	67	83	58	83	55	66	43	52	25	45	23	36	24
98.	TEMP70	9	-1	39	15	46	14	57	33	69	35	85	62	86	65	83	46	59	52	59	32	50	32	36	27
99.	TEMP70	0	-16	40	11	48	25	43	33	82	46	76	52	71	61	74	60	72	51	64	36	45	30	35	34
100.	TEMP70	-4	-21	18	4	47	21	42	38	82	53	70	44	72	50	90	60	78	47	65	29	48	26	34	5
101.	TEMP70	-1	-14	21	-1	38	32	44	38	84	50	61	46	72	45	79	49	84	56	58	42	44	29	15	0
102.	TEMP70	0	-21	42	21	54	24	50	32	87	62	75	45	76	44	80	43	79	62	56	42	48	25	26	1
103.	TEMP70	13	-14	47	30	52	28	68	28	85	57	80	49	78	49	76	54	65	55	57	41	44	9	33	26
104.	TEMP70	14	0	42	21	48	22	62	37	64	54	79	58	78	46	76	48	61	48	60	53	19	7	32	-1
105.	TEMP70	30	11	47	26	50	27	68	36	80	56	82	51	83	52	86	45	64	57	69	49	25	10	16	-4
106.	TEMP70	34	25	26	8	44	29	77	42	69	50	71	41	89	63	90	51	74	48	62	38	38	24	15	1
107.	TEMP70	33	16	42	9	47	28	80	50	62	42	69	49	90	64	91	63	59	39	66	55	38	31	36	-2
108.	TEMP70	32	18	30	16	44	20	83	55	54	38	77	45	87	70	90	59	58	38	66	56	33	28	20	-7
109.	TEMP70	38	30	35	10	32	7	82	56	80	40	81	62	90	67	84	58	57	34	56	33	44	20	19	-12
110.	TEMP70	36	14			38	14	85	51	76	60	91	70	83	68	79	59	70	34	54	33	41	36	23	-8

111.	TEMP70	30 16		48 20	72 60	74 64	93 73	88 68	85 58	67 40	49 37	49 33	25 6
112.	TEMP70	38 21		46 22		78 65		88 64	70 44		46 36		30 17
113.	WIND70	72	329	218	175	418	175	206	163	108	223	276	468
114.	WIND70	60	410	300	336	242	331	142	151	194	276	204	175
115.	WIND70	211	283	228	322	269	276	281	190	238	322	197	350
116.	WIND70	156	420	322	211	238	96	310	156	166	199	302	322
117.	WIND70	144	221	170	338	262	94	120	55	89	295	252	466
118.	WIND70	132	125	254	331	180	101	194	115	305	372	216	223
119.	WIND70	274	149	259	269	300	180	281	144	338	348	144	293
120.	WIND70	394	293	317	391	300	230	305	190	187	350	170	274
121.	WIND70	230	266	254	415	348	290	199	180	235	490	250	307
122.	WIND70	127	228	226	187	290	262	41	166	346	240	235	242
123.	WIND70	163	206	115	346	259	173	46	101	156	168	197	406
124.	WIND70	197	190	166	401	211	242	101	65	250	55	127	250
125.	WIND70	79	110	300	415	362	274	199	142	173	125	334	242
126.	WIND70	230	94	360	252	281	173	211	254	230	281	396	192
127.	WIND70	218	149	281	204	156	221	324	238	245	132	235	161
128.	WIND70	238	238	62	199	259	242	170	242	118	110	175	197
129.	WIND70	293	211	139	262	118	170	245	62	115	293	194	226
130.	WIND70	214	338	242	324	331	336	166	180	120	204	168	178
131.	WIND70	151	305	281	415	194	127	262	84	120	86	209	326
132.	WIND70	322	300	307	379	211	134	266	194	226	132	384	130
133.	WIND70	206	238	142	298	322	214	62	65	298	144	204	240
134.	WIND70	298	218	89	211	245	151	120	211	77	233	533	197
135.	WIND70	163	214	194	355	166	250	182	206	226	254	523	353
136.	WIND70	269	293	175	197	115	286	120	156	274	194	326	206
137.	WIND70	214	370	211	262	300	175	158	72	197	211	422	295
138.	WIND70	166	362	434	250	310	228	139	206	293	266	228	379
139.	WIND70	235	230	298	262	175	86	134	274	204	278	305	240
140.	WIND70	211	120	230	254	190	310	110	108	108	173	238	89
141.	WIND70	329		190	250	293	338	158	290	228	197	254	137
142.	WIND70	226		125	221	221	218	238	314	139	312	324	245
143.	WIND70	250		115		281		108	84		346		154
144.	RAD70	177	256	152	173	369	228	513	680	397	384	107	109
145.	RAD70	194	288	36	586	485	359	646	622	389	388	92	203
146.	RAD70	217	324	44	347	635	775	651	700	287	381	51	44
147.	RAD70	200	118	432	600	710	619	375	407	444	381	215	153
148.	RAD70	250	311	423	425	684	649	762	549	497	375	282	207
149.	RAD70	231	302	415	279	727	691	668	600	75	215	175	214
150.	RAD70	196	79	353	552	653	706	607	490	460	300	216	139
151.	RAD70	224	101	166	464	629	726	527	403	537	70	94	109
152.	RAD70	233	332	419	612	429	671	429	595	483	190	32	162
153.	RAD70	201	249	376	620	663	621	714	550	565	366	222	29
154.	RAD70	103	181	446	507	202	688	696	557	538	323	90	88
155.	RAD70	251	203	477	408	419	475	671	550	156	191	39	40
156.	RAD70	172	370	287	55	166	386	440	570	88	135	71	140
157.	RAD70	150	302	495	599	81	430	501	567	70	379	110	218
158.	RAD70	161	335	499	525	145	344	430	459	155	365	245	151
159.	RAD70	151	345	499	550	369	572	709	637	485	366	243	60
160.	RAD70	138	284	474	652	749	543	686	540	85	359	183	65
161.	RAD70	269	112	461	149	696	604	232	162	485	356	97	50
162.	RAD70	280	373	267	40	625	775	207	387	475	344	87	140
163.	RAD70	265	398	215	190	669	147	700	632	310	112	84	191
164.	RAD70	274	362	527	212	651	697	715	608	181	163	68	103
165.	RAD70	100	385	411	434	490	734	700	382	147	87	218	121

166.	RAD70	270	389	440	655	187	743	701	526	112	60	182	144
167.	RAD70	136	383	469	659	493	675	557	589	101	151	214	208
168.	RAD70	44	433	174	551	624	642	543	484	447	176	143	211
169.	RAD70	212	217	371	584	736	238	590	554	306	175	33	121
170.	RAD70	231	289	384	647	224	667	427	485	413	96	101	208
171.	RAD70	38	311	591	415	590	535	426	393	455	97	221	229
172.	RAD70	246		534	484	364	689	336	315	435	240	61	178
173.	RAD70	228		527	199	245	674	674	449	433	92	36	157
174.	RAD70	293		384		414		602	413		95		106
175.	7011159												
176.	7011169												
177.	7011179												
178.	7011189												
179.	7011191	0	0	0	0	0	0	0	0	0	0	0	0
180.	7011192	0	0	0	0	0	0	0	0	0	0	0	8
181.	7011201	5	5	5	4	4	4	4	3	1	0	0	0
182.	7011202	0	0	0	0	0	0	0	0	0	0	0	0
183.	7011219												
184.	7011229												
185.	7011239												
186.	7011249												
187.	7011259												
188.	7011269												
189.	7011271	0	0	1	1	0	0	0	0	0	0	0	0
190.	7011272	0	0	0	0	0	0	0	0	0	0	0	0
191.	7011289												
192.	7011291	0	0	0	0	0	1	0	0	0	0	0	0
193.	7011292	0	0	0	0	0	0	0	0	0	0	0	0
194.	7011309												
195.	7012 19												
196.	7012 29												
197.	7012 31	0	0	0	0	2	2	0	0	1	0	0	0
198.	7012 32	0	0	0	0	0	0	0	0	0	0	0	0
199.	7012 41	2	0	0	0	0	0	0	0	0	0	0	0
200.	7012 42	0	0	0	0	0	0	0	0	0	0	0	0
201.	7012 59												
202.	7012 69												
203.	7012 79												
204.	7012 89												
205.	7012 99												
206.	7012101	0	0	0	0	0	0	0	0	0	0	0	1
207.	7012102	16	12	7	11	9	24	17	15	5	3	7	7
208.	7012111	8	10	6	5	1	0	0	0	0	0	0	0
209.	7012112	0	0	0	0	1	0	0	0	0	0	0	0
210.	7012121	0	0	0	0	0	0	0	0	0	0	0	0
211.	7012122	0	0	0	0	0	0	0	0	2	2	1	1
212.	7012131	2	1	0	0	0	0	0	0	0	0	0	0
213.	7012132	0	0	0	0	0	0	0	0	0	0	0	0
214.	7012149												
215.	7012159												
216.	7012161	0	0	0	0	0	0	0	2	5	5	4	1
217.	7012162	0	0	0	0	0	0	0	0	0	0	0	0
218.	7012179												
219.	7012189												
220.	7012191	0	0	0	0	0	0	0	1	0	0	0	0

221.	7012192	0	0	0	0	0	0	0	0	0	0	0	0
222.	7012209												
223.	7012211	0	0	0	0	0	0	0	0	0	0	0	0
224.	7012212	0	0	0	0	0	0	0	0	0	0	0	0
225.	7012221	1	1	0	1	1	0	1	1	0	1	1	1
226.	7012222	0	0	0	0	0	0	0	0	0	0	0	0
227.	7012239												
228.	7012249												
229.	7012259												
230.	7012261	0	0	0	0	0	0	0	0	0	2	0	0
231.	7012262	0	0	1	0	0	0	0	0	1	0	0	0
232.	7012279												
233.	7012289												
234.	7012299												
235.	7012309												
236.	7012319												
237.	EVAP71	7	7	42	32	160	78	227	131	105	135	0	12
238.	EVAP71	13	1	40	26	76	83	186	206	169	98	16	7
239.	EVAP71	3	11	44	71	176	201	210	191	148	49	31	4
240.	EVAP71	6	1	46	91	31	199	89	177	153	101	36	4
241.	EVAP71	5	20	16	111	131	214	138	168	144	81	49	11
242.	EVAP71	4	17	30	121	178	194	216	171	135	24	52	4
243.	EVAP71	4	5	34	142	140	122	158	131	156	74	33	1
244.	EVAP71	3	9	54	173	145	235	96	179	149	61	18	6
245.	EVAP71	11	12	31	136	187	201	142	226	120	41	17	6
246.	EVAP71	13	20	47	157	182	124	113	122	157	81	34	4
247.	EVAP71	10	17	14	144	83	155	246	207	144	80	19	36
248.	EVAP71	7	7	13	18	168	249	94	202	132	41	27	13
249.	EVAP71	2	20	25	77	205	211	245	174	128	63	20	7
250.	EVAP71	3	4	17	134	212	183	222	52	144	81	59	0
251.	EVAP71	13	32	10	156	206	177	237	127	134	70	29	5
252.	EVAP71	2	15	62	70	231	221	240	177	102	50	14	19
253.	EVAP71	1	45	69	170	132	251	239	152	117	50	42	21
254.	EVAP71	1	4	9	146	96	148	133	164	43	55	2	9
255.	EVAP71	7	5	29	53	127	168	211	125	1	5	19	5
256.	EVAP71	5	9	86	136	171	161	214	181	43	47	21	2
257.	EVAP71	21	6	56	51	192	235	250	162	87	19	19	17
258.	EVAP71	18	11	55	160	145	192	165	162	83	25	18	22
259.	EVAP71	26	8	70	151	122	211	65	148	71	5	19	27
260.	EVAP71	20	32	66	166	81	189	135	92	102	1	0	17
261.	EVAP71	10	45	57	149	25	93	116	149	17	18	1	2
262.	EVAP71	25	23	64	62	59	182	168	30	18	41	0	3
263.	EVAP71	5	29	35	15	193	262	169	144	77	17	0	0
264.	EVAP71	9	59	41	19	208	270	155	162	103	52	1	10
265.	EVAP71	16		103	70	227	266	146	164	58	13	0	6
266.	EVAP71	17		95	79	217	144	81	116	117	26	11	14
267.	EVAP71	7		103		92		195	67		53		12
268.	TEMP71	35 27	-1-15	30 15	55 28	62 38	69 52	82 58	84 61	87 60	88 63	49 25	29 -1
269.	TEMP71	31 9	14-22	26 11	29 20	58 31	72 51	82 54	77 52	90 68	85 59	51 37	29 3
270.	TEMP71	33 12	24 14	27 7	31 18	65 25	83 45	86 52	75 45	89 69	71 52	44 28	27 10
271.	TEMP71	36 4	35 24	36 5	39 16	55 33	88 56	80 67	76 43	88 69	68 45	44 26	36 12
272.	TEMP71	4-10	37 11	37 29	48 18	72 34	88 64	85 60	83 48	83 68	72 42	58 35	36 33
273.	TEMP71	2-15	17 0	36 26	58 20	66 40	90 63	88 55	83 45	86 59	59 34	35 18	36 33
274.	TEMP71	7-16	9-15	27 17	70 27	68 39	76 54	90 62	83 52	88 54	62 28	33 14	36 33
275.	TEMP71	18-23	4-19	27 8	77 30	75 33	72 46	85 59	88 55	90 65	63 39	36 13	40 33

276.	TEMP71	28	14	8	-15	33	3	63	29	71	36	76	43	82	53	92	72	87	62	54	40	44	29	40	32
277.	TEMP71	27	11	30	8	34	24	70	26	75	35	74	50	81	54	90	60	81	59	61	39	53	25	46	32
278.	TEMP71	21	8	34	16	36	19	77	48	78	34	87	62	82	57	78	54	81	54	62	30	54	20	46	29
279.	TEMP71	15	7	27	-2	36	32	60	38	58	31	94	63	81	51	85	57	78	53	62	29	60	34	35	14
280.	TEMP71	28	14	14	-7	43	32	55	33	77	32	91	62	81	60	90	61	84	52	68	39	48	37	25	12
281.	TEMP71	28	0	24	-6	56	40	56	26	73	35	85	55	83	52	76	57	85	50	70	40	71	41	35	23
282.	TEMP71	12	-5	35	21	40	24	71	31	83	54	86	56	82	58	78	52	72	45	75	36	61	29	38	34
283.	TEMP71	9	-5	35	22	32	22	69	47	79	49	89	53	91	57	82	45	73	38	70	41	61	32	38	22
284.	TEMP71	9	-22	44	30	40	16	72	45	86	47	90	64	80	55	82	50	72	41	76	41	69	46	22	4
285.	TEMP71	13	-26	40	30	34	29	63	39	77	64	90	64	80	55	85	53	62	47	78	52	57	36	26	3
286.	TEMP71	14	-16	40	33	33	27	64	42	70	45	90	63	77	58	86	66	52	46	68	59	39	28	34	17
287.	TEMP71	28	-18	35	25	37	19	78	41	67	42	87	63	83	51	90	59	66	40	76	57	45	27	30	12
288.	TEMP71	33	22	29	21	39	23	56	35	68	34	80	55	91	60	89	63	73	40	69	58	33	12	34	14
289.	TEMP71	36	11	31	27	32	15	60	29	69	33	84	58	87	70	91	59	71	47	70	55	31	8	37	11
290.	TEMP71	32	10	34	23	27	11	68	30	77	54	84	56	76	62	76	54	61	37	56	51	33	24	44	32
291.	TEMP71	37	7	37	16	30	9	58	26	71	54	88	61	83	60	87	54	69	33	58	53	34	20	41	22
292.	TEMP71	37	10	41	17	32	4	66	33	54	45	79	62	85	61	83	52	61	43	63	53	36	31	38	22
293.	TEMP71	23	-6	47	36	38	8	55	36	56	37	84	59	73	51	66	53	65	51	70	54	35	33	36	25
294.	TEMP71	0	-14	37	26	42	33	40	37	66	31	95	67	80	45	75	49	84	61	66	43	33	20	31	9
295.	TEMP71	6	-13	35	21	44	31	45	39	76	35	95	72	74	48	81	47	89	64	65	30	32	19	23	7
296.	TEMP71	31	5			39	26	55	31	77	44	92	73	76	44	85	49	72	46	63	37	32	19	33	20
297.	TEMP71	6	-9			50	26	62	34	82	43	82	67	67	45	86	54	88	54	78	41	28	7	34	24
298.	TEMP71	-4	-13			70	35			71	44			77	43	77	56			50	30			33	14

299.	WIND71	329	290	166	434	336	264	211	314	197	262	211	65
300.	WIND71	180	214	278	396	343	221	156	218	235	218	322	79
301.	WIND71	336	223	269	329	192	108	216	170	266	245	365	108
302.	WIND71	406	240	247	158	226	139	216	233	305	274	252	211
303.	WIND71	290	499	185	163	175	202	168	161	281	281	449	175
304.	WIND71	206	218	408	130	286	233	151	113	274	226	463	134
305.	WIND71	151	134	463	125	175	365	281	115	118	127	245	149
306.	WIND71	182	202	283	362	139	230	218	144	190	252	331	110
307.	WIND71	379	288	103	367	134	199	115	252	274	218	238	242
308.	WIND71	168	271	185	262	130	295	204	295	218	230	170	338
309.	WIND71	211	163	175	334	266	245	254	197	190	235	182	317
310.	WIND71	305	336	180	278	278	211	288	319	120	108	96	250
311.	WIND71	250	228	247	283	218	216	310	226	110	134	317	166
312.	WIND71	266	192	331	161	259	142	182	259	199	276	355	211
313.	WIND71	226	166	487	209	269	151	235	192	182	118	163	377
314.	WIND71	142	310	286	235	144	137	252	120	120	230	182	298
315.	WIND71	151	252	166	247	276	252	125	113	151	187	221	434
316.	WIND71	226	226	317	259	288	242	242	190	194	283	329	235
317.	WIND71	161	259	518	190	418	182	257	240	274	259	386	180
318.	WIND71	293	348	271	132	283	336	144	149	173	163	466	158
319.	WIND71	317	278	250	319	154	166	329	115	194	170	458	245
320.	WIND71	271	492	305	199	221	202	302	199	173	242	166	254
321.	WIND71	324	257	298	298	418	103	137	266	259	254	305	394
322.	WIND71	168	185	113	298	310	182	139	226	142	142	235	290
323.	WIND71	238	173	125	226	358	202	228	214	221	170	274	218
324.	WIND71	458	415	151	218	269	209	257	252	228	305	204	235
325.	WIND71	295	662	338	300	113	252	254	190	221	456	314	259
326.	WIND71	295	341	283	286	96	228	274	118	355	166	190	307
327.	WIND71	386		389	132	168	283	230	130	139	170	434	252
328.	WIND71	372		199	226	146	238	226	144	250	286	197	372
329.	WIND71	336		382		216		211	209		370		283
330.	RAD71	69	265	397	99	624	334	688	379	367	395	40	232

331.	RAD71	204	146	395	220	358	386	616	690	505	329	140	182
332.	RAD71	54	163	458	520	712	707	656	678	443	242	197	147
333.	RAD71	104	68	444	600	172	648	278	632	456	424	278	91
334.	RAD71	226	239	129	613	559	655	476	565	451	339	136	76
335.	RAD71	229	327	277	589	656	577	674	607	453	198	301	74
336.	RAD71	227	286	362	580	544	475	471	481	530	421	297	51
337.	RAD71	218	341	492	569	572	773	352	580	457	278	158	74
338.	RAD71	74	331	372	559	708	688	512	607	372	255	169	105
339.	RAD71	209	222	397	601	685	440	408	366	520	401	255	39
340.	RAD71	148	274	222	434	356	480	717	660	494	412	201	181
341.	RAD71	120	280	158	93	684	707	367	598	488	263	162	131
342.	RAD71	43	366	233	370	718	611	730	551	457	335	174	86
343.	RAD71	196	159	164	637	726	607	703	261	476	361	236	28
344.	RAD71	250	308	85	604	617	575	713	493	495	341	241	37
345.	RAD71	111	207	445	295	721	685	687	636	410	252	145	197
346.	RAD71	245	344	509	625	397	677	755	568	466	281	186	201
347.	RAD71	258	71	99	611	310	438	465	576	179	229	41	68
348.	RAD71	260	51	307	273	483	528	658	403	37	70	105	89
349.	RAD71	151	50	555	515	611	497	690	590	200	187	110	120
350.	RAD71	222	50	424	242	735	741	692	527	378	104	184	193
351.	RAD71	174	50	469	670	591	610	450	521	366	159	226	176
352.	RAD71	243	50	555	574	329	683	277	528	388	43	84	88
353.	RAD71	252	326	560	680	352	584	471	342	475	48	78	180
354.	RAD71	146	399	542	602	89	356	394	505	113	132	37	28
355.	RAD71	285	127	544	330	320	595	591	141	148	179	42	32
356.	RAD71	199	120	219	73	759	714	577	554	299	144	118	26
357.	RAD71	276	428	294	129	745	707	580	591	316	310	112	207
358.	RAD71	156		559	409	743	689	559	577	303	163	129	122
359.	RAD71	312		522	405	714	473	384	412	397	194	224	165
360.	RAD71	278		386		387		694	300		313		206
361.	71 1 11	0	0	0	0	0	1	4	1	0	0	0	0
362.	71 1 12	1	1	1	0	0	0	0	0	0	0	0	0
363.	71 1 29												
364.	71 1 31	0	0	0	0	0	0	0	0	0	3	6	10
365.	71 1 32	6	5	2	4	3	2	1	3	1	1	4	9
366.	71 1 41	5	8	8	4	5	4	2	0	0	0	0	0
367.	71 1 42	0	0	0	0	0	0	0	0	0	0	0	0
368.	71 1 59												
369.	71 1 69												
370.	71 1 79												
371.	71 1 89												
372.	71 1 99												
373.	71 1109												
374.	71 1119												
375.	71 1129												
376.	71 1131	0	0	0	0	0	0	0	0	0	0	0	0
377.	71 1132	0	0	0	1	0	0	0	1	0	0	0	0
378.	71 1149												
379.	71 1159												
380.	71 1161	0	0	0	0	0	0	0	0	0	0	1	4
381.	71 1162	1	3	3	1	1	1	0	1	0	0	0	0
382.	71 1179												
383.	71 1189												
384.	71 1199												
385.	71 1209												

386.	71 1219												
387.	71 1229												
388.	71 1239												
389.	71 1249												
390.	71 1251	0	0	0	0	0	0	0	0	0	0	0	0
391.	71 1252	0	0	0	0	0	0	0	0	0	0	0	1
392.	71 1261	0	1	0	0	0	0	0	0	0	0	0	0
393.	71 1262	0	0	0	0	0	0	0	0	0	0	0	0
394.	71 1271	0	0	0	0	0	0	0	0	0	0	0	0
395.	71 1272	0	0	0	0	1	0	1	0	0	1	0	0
396.	71 1289												
397.	71 1291	0	0	0	0	0	1	0	1	5	7	4	0
398.	71 1292	0	0	0	1	0	0	1	0	0	0	0	0
399.	71 1309												
400.	71 1319												
401.	71 2 19												
402.	71 2 21	0	0	0	0	0	0	0	0	0	0	0	0
403.	71 2 22	1	0	0	0	0	0	0	0	0	0	0	0
404.	71 2 39												
405.	71 2 41	0	0	0	1	0	0	1	0	0	0	0	0
406.	71 2 42	0	0	0	0	0	0	4	6	5	5	7	7
407.	71 2 51	3	0	1	1	0	0	0	0	0	0	0	0
408.	71 2 52	0	0	0	0	0	0	0	0	0	0	0	0
409.	71 2 69												
410.	71 2 79												
411.	71 2 89												
412.	71 2 99												
413.	71 2109												
414.	71 2111	0	0	0	0	0	0	0	0	0	0	0	0
415.	71 2112	0	0	0	0	0	0	0	0	0	1	0	0
416.	71 2129												
417.	71 2139												
418.	71 2149												
419.	71 2159												
420.	71 2161	0	0	0	0	0	0	0	0	0	0	0	0
421.	71 2162	0	0	0	0	0	0	0	0	1	2	0	0
422.	71 2179												
423.	71 2181	0	0	0	0	0	0	0	0	0	0	0	0
424.	71 2182	4	7	0	4	9	3	12	1	4	2	8	5
425.	71 2191	3	0	0	0	1	1	6	7	15	3	5	13
426.	71 2192	1	0	0	0	0	7	5	0	3	4	5	7
427.	71 2201	3	2	3	6	8	1	1	0	0	0	0	0
428.	71 2202	0	0	0	0	0	0	0	0	0	0	0	0
429.	71 2219												
430.	71 2221	0	0	0	0	0	0	0	0	2	5	11	14
431.	71 2222	3	2	0	0	0	0	0	0	0	0	0	1
432.	71 2231	0	0	0	1	0	0	0	0	0	0	0	0
433.	71 2232	0	0	0	0	0	0	0	0	0	0	0	0
434.	71 2249												
435.	71 2259												
436.	71 2261	0	0	0	0	0	0	0	0	2	0	0	0
437.	71 2262	0	0	0	3	0	0	0	0	0	0	0	0
438.	71 2279												
439.	71 2289												
440.	71 3 19												

441.	71 3 29												
442.	71 3 39												
443.	71 3 49												
444.	71 3 51	0	0	0	0	0	0	0	0	0	0	0	0
445.	71 3 52	0	0	0	0	0	2	8	6	4	1	1	2
446.	71 3 61	1	0	0	1	0	0	0	0	0	0	0	0
447.	71 3 62	0	0	0	0	0	0	0	0	0	0	0	0
448.	71 3 71	0	0	0	0	0	0	0	0	0	0	0	0
449.	71 3 72	0	0	0	0	0	1	0	0	0	0	0	0
450.	71 3 89												
451.	71 3 99												
452.	71 3109												
453.	71 3119												
454.	71 3121	0	0	0	0	0	0	0	2	2	1	0	0
455.	71 3122	0	0	0	0	0	0	0	0	0	0	0	0
456.	71 3139												
457.	71 3141	0	0	0	0	0	0	0	0	0	0	0	0
458.	71 3142	0	0	0	0	0	0	1	0	15	1	0	0
459.	71 3151	0	0	0	0	0	0	0	0	0	0	0	0
460.	71 3152	0	0	0	1	5	0	0	0	0	0	0	0
461.	71 3169												
462.	71 3179												
463.	71 3181	0	0	0	0	0	0	0	0	3	4	3	2
464.	71 3182	4	4	4	4	3	4	8	10	8	3	8	8
465.	71 3191	2	3	1	2	1	3	1	1	0	0	0	1
466.	71 3192	0	0	0	0	0	0	0	0	0	0	0	0
467.	71 3209												
468.	71 3219												
469.	71 3229												
470.	71 3239												
471.	71 3249												
472.	71 3259												
473.	71 3269												
474.	71 3271	0	0	0	0	0	0	0	0	0	0	2	0
475.	71 3272	0	0	0	0	0	0	0	0	0	0	0	0
476.	71 3289												
477.	71 3299												
478.	71 3309												
479.	71 3319												
479.1	/*												

APPENDIX E

NPS MODEL SOURCE LISTING

```
//A12YJL  JOB (A12$X2,510,0.5,25),REGION=300K
/*JOBPARM COPIES=2
//STEP1 EXEC FORTHCL,LEVEL=H,PARM.FORT='OPT=1,MAP,XREF'
//FORT.SYSIN DD *
C
C
C
C
C        ************************************************************
C        *                                                          *
C        *          NONPOINT SOURCE POLLUTANT LOADING (NPS) MODEL   *
C        *                                                          *
C        ************************************************************
C
C                                   DEVELOPED BY:  HYDROCOMP, INCORPORATED
C                                                  1502 PAGE MILL ROAD
C                                                  PALO ALTO, CA.  94304
C                                                    415-493-5522
C
C                                            FOR:  U.S. ENVIRONMENTAL
C                                                   PROTECTION AGENCY
C                                                  OFFICE OF RESEARCH
C                                                   AND DEVELOPMENT
C                                                  SOUTHEAST ENVIRONMENTAL
C                                                   RESEARCH LABORATORY
C                                                  ATHENS, GA.  30601
C                                                    404-546-3587
C
C
C                                   NPS - MAIN PROGRAM
C
      IMPLICIT  REAL(L)
C
      DIMENSION MNAM(24),RAD(24),TEMPX(24),WINDX(24),RAIN(96),
     1          IRAIN(96),IRAD(12,31),IEVAP(12,31),IWIND(12,31),
     2          ITEMP(12,31,2),SRAD(24),RADDIS(24),WINDIS(24),
     3          AR1OUT(28),AR2OUT(28),COVVEC(12),REPERM(5,12),TCF(12),
     4          TOTAL(24),VMIN(24),VMAX(24),SD(24),RANGE(24),AVER(24),
     5          REIMPM(5,12),ACUIM(5,12),PMPTAB(5,5,12),PMITAB(5,5,12),
     6          ACUPM(5,12)
C
      COMMON /ALL/ RU,HYMIN,HYCAL,DPST,UNIT,TIMFAC,LZS,AREA,RESB,SFLAG,
     1             RESB1,ROSB,SRGX,INTF,RGX,RUZB,UZSB,PERCB,RIB,P3,TF,
     2             KGPLB,LAST,PREV,TEMPX,IHR,IHRR,PR,RUI,A,PA,GWF,NOSY,
     3             SRER(5),TS(5),LNDUSE(3,5),AR(5),QUALIN(3,5),NOSI,NOS,
     4             NOSIM,UFL,UTMP,UNT1(2,2),UNT2(2,2),UNT3(2,2),WHGT,
     5             WHT,DEPW,ROSBI,RESBI,RESBI1,ARUN,LMTS(5),IMPK(5),
     6             NLAND,NQUAL,STMCH(200,24),RECOUT(5),FLOUT,SCALEF(5),
     7             SNOW,PACK,IPACK
C
      COMMON /LAND/DAY,PRTM,IMIN,IX,TWBAL,SGW,GWS,KV,LIRC4,LKK4,ALTR(9),
     1             UZS,IZ,UZSN,LZSN,INFIL,INTER,SGW1,DEC,DECI,TIT(13),
     2             K24L,KK24,K24EL,EP,IFS,K3,EPXM,RESS1,RESS,SCEP,IRC,
     3             SRGXT1,MMPIN,KGPHA,METOPT,CCFAC,SCEP1,SRGXT,RAIN,SRC,
```

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     4              SCF,IDNS,F,DGM,WC,MPACK,EVAPSN,MELEV,TSNOW,PETMIN,
     5              DEWX,DEPTH,MONTH,TMIN,PETMAX,ELDIF,SDEN,WINDX,INFTOM,
     6              TSNBAL,ROBTOM,ROBTOT,RXB,ROITOM,ROITOT,YEAR,CUNIT(7),
     7              INFTOT,MNAM,RAD,SRCI,FORM(42)
C
      COMMON /QLS/ WSNAME(6),KRER,JRER,KSER,JSER,TEMPCF,COVMAT(5,12),
     1             KEIM,JEIM,NDSR,ARP(5),ARI(5),ACCP(5),ACCI(5),RPER(5),
     2             PMP(5,5),PMI(5,5),QSNOW,SNOWY,SEDTM,SEDTY,SEDTCA,
     3             ACPOLP(5,5),ACERSN(5),APOLP(5,5),AERSN(5),COVER(5),
     4             APOLI(5,5),ACEIM(5),AEIM(5),POLTM(5),POLTY(5),
     5             TEMPA,DOA,POLTCA(5),AERSNY(5),AEIMY(5),APOLPY(5,5),
     6             APOLIY(5,5),POLTC(5),PLTCAY(5),ACPOLI(5,5),RIMP(5)
C
      COMMON /LNDOUT/ ROSTOM,RINTOM,RITOM,RUTOM,BASTOM,RCHTOM,PRTOM,
     1                SUMSNM,PXSNM,MELRAM,RADMEM,CONMEM,CDRMEM,
     2                DRAINM,SGMM,SNEGMM,PACKOT,SEVAPM,EPTOM,NEPTOM,
     3                UZSOT,LZSOT,SGWOT,SCEPOT,RESSOT,SRGXTO,TWBALO,
     4                TSNBOL,ROSTOT,RINTOT,RITOT,RUTOT,BASTOT,RCHTOT,
     5                PRTOT,SUMSNY,PXSNY,MELRAY,RADMEY,CONMEY,CDRMEY,
     6                DRAINY,SGMY,SNEGMY,PACK1,SEVAPY,EPTOT,NEPTOT,
     7                UZSMT,LZSMT,SGWMT,SCEPT,RESST,SRGXTT,TWBLMT
C
      COMMON /INTM/ RTYPE(4,4),UTYPE(2),GRAD,RADDIS,WINDIS,ICS,OPS,
     1              TEMPAY,DOAY,NDSIY,INTRVL,WMUL,NN,L,SS,NNI,LI,SSI,
     2              RMUL,KUGI,SEDTCY,REPERV(12),REIMPV(12),ACUPV(12),
     3              ACUIV(12),PMPMAT(12,5),PMIMAT(12,5),PMPVEC(5),
     4              PMIVEC(5),ACUI,ACUP,REIMP,REPER,PRINTR
C
      EQUIVALENCE (ROSTOM,AR1OUT(1)),(TSNBOL,AR2OUT(1))
C
      LOGICAL LAST, PREV
C
      INTEGER  BGNDAY, BGNMON, BGNYR, ENDDAY, ENDMON, ENDYR,
     1         DYSTRT, DYEND, YEAR, DAY, H, HYCAL, TIME, PINT, PRINTR,
     2         YR, CN, TF, DA, DY, UNIT, SNOW, LMTS, RECOUT, SFLAG
C
      REAL  IRC, NN, NNI, KV, K24L, KK24, INFIL, INTER,
     1      IFS, ICS, K24EL, K3, NEPTOM, NEPTOT, IDNS, MPACK,
     2      JRER, KRER, JSER, KSER,KEIM,JEIM, MELEV, KUGI,
     3      K1, KK4, IRC4, MELRAM, MELRAY, IPACK, IMPKO,
     4      INFTOM, INFTOT, IMPK, MMPIN, METOPT,
     5      KGPLB,KGPHA
C
      REAL*8  WSNAME,RTYPE,UTYPE
C
C                   NAMELIST INPUT VARIABLES
C
      NAMELIST /ROPT/  HYCAL, HYMIN, NLAND, NQUAL, SNOW
      NAMELIST /DTYP/  UNIT, PINT, MNVAR
      NAMELIST /STRT/  BGNDAY, BGNMON, BGNYR
      NAMELIST /ENDD/  ENDDAY, ENDMON, ENDYR
      NAMELIST /LND1/  UZSN, LZSN, INFIL, INTER ,IRC, AREA
      NAMELIST /LND2/  NN, L, SS, NNI, LI, SSI
      NAMELIST /LND3/  K1, PETMUL, K3 ,EPXM, K24L, KK24
      NAMELIST /LND4/  UZS, LZS, SGW
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      NAMELIST /SNO1/  RADCON, CCFAC, EVAPSN
      NAMELIST /SNO2/  MELEV, ELDIF, TSNOW
      NAMELIST /SNO3/  MPACK, DGM, WC, IDNS
      NAMELIST /SNO4/  SCF, WMUL, RMUL, F, KUGI
      NAMELIST /SNO5/  PACK, DEPTH
      NAMELIST /WSCH/  ARFRAC ,IMPKO, COVVEC
      NAMELIST /YPTM/  PMPVEC, PMIVEC
      NAMELIST /MPTM/  PMPMAT,PMIMAT
      NAMELIST /WASH/  JRER, KRER, JSER ,KSER, JEIM, KEIM, TCF
      NAMELIST /YACR/  ACUP,ACUI
      NAMELIST /MACR/  ACUPV,ACUIV
      NAMELIST /YRMR/  REPER, REIMP
      NAMELIST /MRMR/  REPERV,REIMPV
      NAMELIST /INAC/  SRERI, TSI
C
C          NAMELIST INPUT PARAMETER DESCRIPTION
C  HYCAL : INDICATES TYPE OF SIMULATION RUN
C        =  1  HYDROLOGIC CALIBRATION
C        =  2  SEDIMENTS AND QUALITY CALIBRATION
C        =  3  PRODUCTION RUN (PRINTER OUTPUT)
C        =  4  PRODUCTION RUN (PRINTER & W/O HEADINGS OUTPUT ON UNIT 4)
C  HYMIN : MINIMUM FLOW FOR OUTPUT DURING A TIME INTERVAL (CFS, CMS)
C  UNIT  : ENGLISH(-1), METRIC(1)
C  NLAND : NUMBER OF LAND TYPE USES IN THE WATERSHED
C  NQUAL : NUMBER OF QUALITY CONSTITUENTS SIMULATED
C  SNOW  : (0) SNOWMELT NOT PERFORMED, (1) SNOWMELT CALC'S PERFORMED
C  MNVAR : MONTHLY VARIATION IN ACCUMULATION RATES, REMOVAL RATES,
C          AND POTENCY FACTORS USED (1), OR NOT USED (0)
C  PINT  : INPUT PRECIPITATION IN INTERVALS OF 15 MIN.(0), OR HOURLY (1)
C  BGNDAY, BGNMON, BGNYR : DATE SIMULATION BEGINS
C  ENDDAY, ENDMON, ENDYR : DATE SIMULATION ENDS
C  UZSN  : NOMINAL UPPER ZONE STORAGE (IN, MM)
C  LZSN  : NOMINAL LOWER ZONE STORAGE (IN, MM)
C  INFIL : INFILTRATION RATE (IN/HR, MM/HR)
C  INTER : INTERFLOW PARAMETER, ALTERS RUNOFF TIMING
C  IRC   : INTERFLOW RECESSION RATE
C  AREA  : WATERSHED AREA IN ACRES
C  NN    : MANNING'S N FOR OVERLAND PERVIOUS FLOW
C  NNI   : MANNING'S N FOR OVERLAND IMPERVIOUS FLOW
C  L     : LENGTH OF OVERLAND PERVIOUS FLOW TO CHANNEL (FT, M)
C  LI    : LENGTH OF OVERLAND IMPERVIOUS FLOW TO CHANNEL (FT, M)
C  SS    : AVERAGE OVERLAND PERVIOUS FLOW SLOPE
C  SSI   : AVERAGE OVERLAND IMPERVIOUS FLOW SLOPE
C  K1    : RATIO OF SPATIAL AVERAGE RAINFALL TO GAGE RAINFALL
C  K3    : INDEX TO ACTUAL EVAPORATION
C  PETMUL: POTENTIAL EVAPOTRANSPIRATION MULTIPLICATION FACTOR
C  K24L  : FRACTION OF GROUNDWATER RECHARGE PERCOLATING TO DEEP
C          GROUNDWATER
C  KK24  : GROUNDWATER RECESSION RATE
C  UZS   : INITIAL UPPER ZONE STORAGE (IN, MM)
C  LZS   : INITIAL LOWER ZONE STORAGE (IN, MM)
C  SGW   : INITIAL GROUNDWATER STORAGE (IN, MM)
C  RADCON: CORRECTION FACTOR FOR RADIATION
C  CCFAC : CORRECTION FACTOR FOR CONDENSATION AND CONVECTION
C  SCF   : SNOW CORRECTION FACTOR FOR RAINGAGE CATCH DEFICIENCY
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      C  ELDIF : ELEVATION DIFFERENCE FROM TEMP. STATION TO MEAN SEGMENT ELEVA
      C           (1000 FT, KM)
      C  IDNS  : DENSITY OF NEW SNOW AT 0 DEGREES F.
      C  F     : FRACTION OF SEGMENT WITH COMPLETE FOREST COVER
      C  DGM   : DAILY GROUNDMELT (IN/DAY, MM/DAY)
      C  WC    : MAXIMUM WATER CONTENT OF SNOWPACK BY WEIGHT
      C  MPACK : ESTIMATED WATER EQUIVALENT OF SNOWPACK FOR COMPLETE COVERAGE
      C  EVAPSN: CORRECTION FACTOR FOR SNOW EVAPORATION
      C  MELEV : MEAN ELEVATION OF WATERSHED (FT, M)
      C  TSNOW : TEMPERATURE BELOW WHICH SNOW FALLS (F, C)
      C  PACK  : INITIAL WATER EQUIVALENT OF SNOWPACK (IN, MM)
      C  DEPTH : INITIAL DEPTH OF SNOWPACK (IN, MM)
      C  ARFRAC: PERCENT OF A GIVEN LAND TYPE USE
      C  IMPKO : PERCENTAGE OF IMPERVIOUS AREA FOR A GIVEN LAND TYPE USE
      C  COVVEC: MONTHLY COVER COEFF. FOR A GIVEN LAND TYPE USE
      C  PMPVEC: POTENCY VECTOR FOR A GIVEN LAND TYPE - PERVIOUS AREAS
      C  PMIVEC: POTENCY VECTOR FOR A GIVEN LAND TYPE - IMPERVIOUS AREAS
      C  TCF   : TEMPERATURE CORRECTION FACTOR RELATING RUNOFF AND
      C          AIR TEMPERATURES
      C  JRER  : EXPONENT IN RAINDROP SOIL SPLASH EQUATION
      C  KRER  : COEF. IN RAINDROP SOIL SPLASH EQUATION
      C  JSER  : EXPONENT IN WASH OFF FUNCTION FOR PERVIOUS AREAS
      C  KSER  : COEF. IN WASH OFF FUNCTION FOR PERVIOUS AREAS
      C  JEIM  : EXPONENT IN WASH OFF FUNCTION FOR IMPERVIOUS AREAS
      C  KEIM  : COEF. IN WASH OFF FUNCTION FOR IMPERVIOUS AREAS
      C  ACUI  : ACCUMULATION RATES - IMPERVIOUS AREAS
      C  ACUP  : ACCUMULATION RATES - PERVIOUS AREAS
      C  REIMP : REMOVAL COEF. -IMPERVIOUS AREAS
      C  REPER : REMOVAL COEF. - PERVIOUS AREAS
      C  SRERI : INITIAL AMOUNT OF FINES AVAILABLE FOR TRANSPORT
      C  TSI   : INITIAL AMOUNT OF SOLIDS AVAILABLE FOR TRANSPORT
      C
            READ (5,4520) (WSNAME(I),I=1,6)
            READ (5,ROPT)
            READ (5,DTYP)
            READ (5,STRT)
            READ (5,ENDD)
            READ (5,LND1)
            READ (5,LND2)
            READ (5,LND3)
            READ (5,LND4)
            IF (SNOW .LT. 1) GO TO 20
            QSNOW=SNOWY
            READ (5,SNO1)
            READ (5,SNO2)
            READ (5,SNO3)
            READ (5,SNO4)
            READ (5,SNO5)
         20 READ (5,WASH)
            DO 30 J=1,NQUAL
         30 READ (5,4060) (QUALIN (I,J),I=1,3),CUNIT(J)
            DO 100 II=1,NLAND
            READ (5,4060) (LNDUSE(K,II),K=1,3)
            READ (5,WSCH)
            AR(II)=ARFRAC
```

```
      IMPK(II)=IMPKO
      DO 40 IJ=1,12
   40 COVMAT(II,IJ)=COVVEC(IJ)
      IF (MNVAR.EQ.1) GO TO 60
C
C           READ INPUT DATA OF ACCUMULATION RATES, REMOVAL RATES, AND
C           POTENCY MATRICES WITHOUT MONTHLY VARIATION
C
      READ (5,YPTM)
      READ (5,YACR)
      READ (5,YRMR)
      DO 50 IJ=1,NQUAL
      PMPTAB(IJ,II,BGNMON)=PMPVEC(IJ)
   50 PMITAB(IJ,II,BGNMON)=PMIVEC(IJ)
      ACUPM(II,BGNMON)=ACUP
      ACUIM(II,BGNMON)=ACUI
      REPERM(II,BGNMON)=REPER
      REIMPM(II,BGNMON)=REIMP
      GO TO 90
C
C           READ INPUT DATA OF ACCUMULATION RATES, REMOVAL RATES, AND
C           POTENCY MATRICES WITH MONTHLY VARIATION
C
   60 READ (5,MPTM)
      READ (5,MACR)
      READ (5,MRMR)
      DO 70 IJ=1,NQUAL
      DO 70 MN=1,12
      PMPTAB(IJ,II,MN)=PMPMAT(MN,IJ)
   70 PMITAB(IJ,II,MN)=PMIMAT(MN,IJ)
      DO 80 MN=1,12
      ACUPM(II,MN)=ACUPV(MN)
      ACUIM(II,MN)=ACUIV(MN)
      REPERM(II,MN)=REPERV(MN)
   80 REIMPM(II,MN)=REIMPV(MN)
   90 CONTINUE
      READ (5,INAC)
      SRER(II)=SRERI
      TS(II)=TSI
  100 CONTINUE
      IF (UNIT .EQ. -1) GO TO 120
      DEPW=UNT1(2,1)
      WHGT=UNT1(1,1)
      WHT=UNT2(1,1)
      UPL=UNT2(2,1)
      UTMP=UNT3(1,1)
      ARUN=UNT3(2,1)
      KUNT=1
      GO TO 130
  120 DEPW=UNT1(2,2)
      WHGT=UNT1(1,2)
      WHT=UNT2(1,2)
      UPL=UNT2(2,2)
      UTMP=UNT3(1,2)
      ARUN=UNT3(2,2)
```

```
      KUNT=2
C
C                     PRINTING OF TITLE PAGE AND INPUT PARAMETERS
C
  130 WRITE (6,4070)
      WRITE (6,4080) (WSNAME(I),I=1,6),ARUN,APEA
      WRITE (6,4090) ARUN,ARUN,ARUN
      ARPT=0.0
      ARIT=0.0
      DO 140 I=1,NLAND
      TEM=AREA*AR(I)
      ARP(I)=TEM*(1.-IMPK(I))
      ARPT=ARPT+ARP(I)
      ARI(I)=TEM*IMPK(I)
      ARIT=ARIT+ARI(I)
      AR(I)=AR(I)*100.
      PER=IMPK(I)*100.
      WRITE (6,4100) (LNDUSE(KK,I),KK=1,3),AR(I),TEM,ARP(I),ARI(I),PER
      AR(I)=TEM
  140 CONTINUE
      A=ARIT/AREA
      WRITE (6,4110) A
      IF (ABS((ARIT+ARPT-AREA)/AREA).LE.0.001) GO TO 150
      WRITE (6,4120)
      GO TO 1600
C
C                     PRINTING OF SIMULATION CHARACTERISTICS
C
  150 IZ=BGNMON*2-1
      IX=IZ+1
      IP=ENDMON*2-1
      IQ=IP+1
      NQI=NQUAL+3
      IF (PINT.EQ.1) PRINTR=60
      WRITE (6,4130) (RTYPE(HYCAL,I),I=1,4),MNAM(IZ),MNAM(IX),BGNDAY,
     *               BGNYR,MNAM(IP),MNAM(IQ),ENDDAY,ENDYR,PRINTR,INTRVL,
     *               QSNOW,UTYPE(KUNT),UTYPE(KUNT),UFL,
     *               HYMIN,NQI,((QUALIN(I,J),I=1,3),J=1,NQUAL)
      WRITE (6,4140) INTER,IRC,INFIL,NN,L,SS,NNI,LI,SSI,K1,
     *               PETMUL,K3,EPXM,K24L,KK24,UZSN,LZSN
      IF (SNOW.EQ.1) WRITE (6,4150) RADCON,CCFAC,EVAPSN,MELEV,
     *                              ELDIF,TSNOW,MPACK,DGM,WC,IDNS,SCF,
     *                              WMUL,RMUL,F,KUGI
      WRITE (6,4160) JRER,KRER,JSER,KSER,JEIM,KEIM
      IF (MNVAR.EQ.1) GO TO 200
C
C           PRINTING OF ACCUMULATION RATES,REMOVAL RATES,
C           AND POTENCY FACTORS WITHOUT MONTHLY VARIATION
C
      DO 160 I=1,NLAND
  160 WRITE (6,4230) (LNDUSE(K,I),K=1,3),ACUPM(I,BGNMON),ACUIM(I,BGNMON)
      WRITE (6,4010)
      DO 170 I=1,NLAND
  170 WRITE (6,4240) (LNDUSE(KK,I),KK=1,3),REPERM(I,BGNMON),
     *                REIMPM(I,BGNMON)
```

```
      WRITE (6,4250) ((LNDUSE(KK,I),KK=1,3),I=1,NLAND)
      DO 180 I=1,NQUAL
  180 WRITE (6,4260) (QUALIN(J,I),J=1,3),(PMPTAB(I,K,BGNMON),K=1,NLAND)
      WRITE (6,4270) ((LNDUSE(KK,I),KK=1,3),I=1,NLAND)
      DO 190 I=1,NQUAL
  190 WRITE (6,4260) (QUALIN(J,I),J=1,3),(PMITAB(I,K,BGNMON),K=1,NLAND)
C
C        PRINTING OF MONTHLY COVER FUNCTION AND TEMP CORRECTION FACTORS
C
  200 WRITE (6,4170) (MNAM(I),I=1,24,2),(TCF(I),I=1,12),
     *          (LNDUSE(KK,1),KK=1,3),(COVMAT(1,KK),KK=1,12)
      IF (NLAND.EQ.1) GO TO 220
      DO 210 I=2,NLAND
  210 WRITE (6,4180) (LNDUSE(KK,I),KK=1,3),(COVMAT(I,KK),KK=1,12)
  220 IF (MNVAR.EQ.0) GO TO 290
C
C             PRINTING OF ACCUMULATION RATES,REMOVAL RATES,
C             AND POTENCY FACTORS WITH MONTHLY VARIATION
C
      WRITE (6,4190)
      DO 230 I=1,NLAND
  230 WRITE (6,4180) (LNDUSE(KK,I),KK=1,3),(ACUPM(I,J),J=1,12)
      WRITE (6,4200)
      DO 240 I=1,NLAND
  240 WRITE (6,4180) (LNDUSE(KK,I),KK=1,3),(REPERM(I,J),J=1,12)
      DO 250 J=1,NQUAL
      WRITE (6,4210) (QUALIN(KK,J),KK=1,3)
      DO 250 I=1,NLAND
  250 WRITE (6,4180) (LNDUSE(KK,I),KK=1,3),(PMPTAB(J,I,K),K=1,12)
      WRITE (6,4220)
      WRITE (6,4190)
      DO 260 I=1,NLAND
  260 WRITE (6,4180) (LNDUSE(KK,I),KK=1,3),(ACUIM(I,J),J=1,12)
      WRITE (6,4200)
      DO 270 I=1,NLAND
  270 WRITE (6,4180) (LNDUSE(KK,I),KK=1,3),(REIMPM(I,J),J=1,12)
      DO 280 J=1,NQUAL
      WRITE (6,4210) (QUALIN(KK,J),KK=1,3)
      DO 280 I=1,NLAND
  280 WRITE (6,4180) (LNDUSE(KK,I),KK=1,3),(PMITAB(J,I,K),K=1,12)
C
C            PRINTING OF INITIAL CONDITIONS
C
  290 WRITE (6,4280) UZS,LZS,SGW
      IF (SNOW.EQ.1) WRITE (6,4290) PACK,DEPTH
      WRITE (6,4300) (LNDUSE(KK,1),KK=1,3),TS(1),SRER(1)
      IF (NLAND.EQ.1) GO TO 310
      DO 300 I=2,NLAND
  300 WRITE (6,4310) (LNDUSE(KK,I),KK=1,3),TS(I),SRER(I)
  310 IF (UNIT.EQ.-1) GO TO 350
C
C  CONVERSION OF METRIC INPUT DATA TO ENGLISH UNITS
C
      HYMIN= HYMIN*35.3
      UZSN = UZSN/MMPIN
```

```
      LZSN = LZSN/MMPIN
      INFIL= INFIL/MMPIN
      L    = L*3.281
      LI   = LI*3.281
      UZS  = UZS/MMPIN
      LZS  = LZS/MMPIN
      SGW  = SGW/MMPIN
      ICS  = ICS/MMPIN
      OFS  = OFS/MMPIN
      IFS  = IFS/MMPIN
      EPXM = EPXM/MMPIN
      AREA = AREA*2.471
      DO 340 I=1,NLAND
      AR(I)=AR(I)*2.471
      ARP(I)=ARP(I)*2.471
      ARI(I)=ARI(I)*2.471
      SRER(I)=SRER(I)*KGPHA
      TS(I)=TS(I)*KGPHA
      IF (MNVAR.GT.0) GO TO 320
      ACUPM(I,BGNMON)=ACUPM(I,BGNMON)*KGPHA
      ACUIM(I,BGNMON)=ACUIM(I,BGNMON)*KGPHA
      GO TO 340
  320 DO 330 J=1,12
      ACUPM(I,J)=ACUPM(I,J)*KGPHA
  330 ACUIM(I,J)=ACUIM(I,J)*KGPHA
  340 CONTINUE
      DO 345 I=7,37,6
  345 FORM(I)=ALTR(2)
      IF (SNOW.LT.1) GO TO 350
      ELDIF = ELDIF/0.3048
      DGM   = DGM/MMPIN
      MELEV = MELEV/0.3048
      TSNOW = 1.8*TSNOW + 32.0
      PACK  = PACK/MMPIN
      DEPTH = DEPTH/MMPIN
C
C                        ADJUSTMENT OF CONSTANTS
C
  350 H = 60/INTRVL
      TIMFAC = INTRVL
      INTRVL = 24*H
      ARIT=0.0
      KRER=KRER*H**(JRER-1.0)
      KSER=KSER*H**(JSER-1.0)
      KEIM=KEIM*H**(JEIM-1.0)
      DO 355 I=1,NQUAL
      IF (CUNIT(I).EQ.TIT(1)) CUNIT(I)=CUNIT(7)
  355 IF (CUNIT(I).EQ.CUNIT(6)) SCALEF(I)=1000.
      IF (NQUAL.EQ.5) GO TO 357
      II=11+NQUAL*6
      DO 356 I=II,40
  356 FORM(I)=ALTR(1)
  357 I=NQUAL+4
      TIT(1)=ALTR(I)
      J=0
```

```
      DO 358 I=15,39,6
      J=J+1
      IF(SCALEF(J).LE.2.) GO TO 358
      FORM(I)=ALTR(3)
  358 CONTINUE
C
C           CONVERT ACCUMULATION RATES INTO TONS/ACRE/DAY
C
      DO 380 I=1,NLAND
      TS(I)=TS(I)/2000.
      SRER(I)=SRER(I)/2000.
      IF (MNVAR.GT.0) GO TO 360
      ACUPM(I,BGNMON)=ACUPM(I,BGNMON)/2000.
      ACUIM(I,BGNMON)=ACUIM(I,BGNMON)/2000.
      GO TO 380
  360 DO 370 J=1,12
      ACUIM(I,J)=ACUIM(I,J)/2000.
      ACUPM(I,J)=ACUPM(I,J)/2000.
  370 CONTINUE
  380 CONTINUE
        PA=1.0-A
        IRC4=IRC**(1.0/96.0)
        LIRC4=1.0-IRC4
        KK4=KK24**(1.0/96.0)
        LKK4= 1.0 - KK4
C
      IF ((24.*60./TIMFAC) .GT. 100.)  GO TO 390
      GO TO 400
  390 LIRC4 = LIRC4/3.0
      LKK4 = LKK4/3.0
  400 DEC= 0.00982*((NN*L/SQRT(SS))**0.5)
      SRC= 1020.*SQRT(SS)/(NN*L)
      DECI= 0.00982*((NNI*LI/SQRT(SSI))**0.6)
      SRCI= 1020.*SQRT(SSI)/(NNI*LI)
C                                    INITIALIZE TEMP DIST VARIABLES
      TEMPI = 35.
      CHANGE = -12.
      GRAD(1)=0.04
      GRAD(2)=0.04
C
C                                    INITIALIZE IPACK
      IPACK=0.01
          UZSB = UZS
          RESB = OFS
          SRGX = IFS
C
      RESS1 = OFS
      RESS = OFS
      SCEP = ICS
      SCEP1 = ICS
      SRGXT = IFS
      SRGXT1 = IFS
      SGW1 = SGW
C
C                               PROGRAM EXECUTION
```

```
      C                                                    BEGIN YEARLY LOOP
            DO 1590  YEAR=BGNYR,ENDYR
               MNSTRT = 1
               MNEND = 12
               IF (YEAR .EQ. BGNYR)  MNSTRT = BGNMON
               IF (YEAR .EQ. ENDYR)  MNEND = ENDMON
      C
      C
      C  EVAP, TEMP(MAX-MIN), RAD, AND WIND  DATA INPUT
      C
      C
      C
             DO  410  DA = 1,31
        410   READ (5,4050) (IEVAP(MN,DA), MN =1,12)
      C
      C
              DO  420 DA = 1,31
        420   READ(5,4040) ((ITEMP(MN,DA,IT), IT=1,2),MN=1,12)
      C
            IF (SNOW .LT. 1)  GO TO 450
              DO  430 DA = 1,31
        430   READ(5,4050) (IWIND(MN,DA), MN=1,12)
      C
              DO 440 DA =1,31
        440   READ (5,4050) (IRAD(MN,DA), MN=1,12)
      C
        450   IF (UNIT .EQ. -1) GO TO 490
              DO 480 DA=1,31
                 DO 470 MN=1,12
                    IEVAP(MN,DA) = IEVAP(MN,DA)*3.937
                   IF (SNOW.EQ.1) IWIND(MN,DA) = IWIND(MN,DA)*0.6214
                     DO 460 IT=1,2
        460          ITEMP(MN,DA,IT) = 1.8*ITEMP(MN,DA,IT) + 32.5
        470         CONTINUE
        480      CONTINUE
      C                                      SAV TMIN OF JAN 1 ON 11/31
        490 ITEMP(11,31,2) = ITEMP(1,1,2)
      C
      C
      C
      C                                                     BEGIN MONTHLY LOOP
        500    DO 1240  MONTH=MNSTRT,MNEND
      C
      C              ASSIGN CURRENT MONTHLY VALUES OF ACCUMULATION RATES,
      C              REMOVAL RATES, AND POTENCY FACTORS
      C
            IF (HYCAL.EQ.1) GO TO 530
            IF (MNVAR.EQ.0.AND.MONTH.NE.BGNMON) GO TO 530
            DO 520 I=1,NLAND
            DO 510 J=1,NQUAL
            PMP(J,I)=PMPTAB(J,I,MONTH)
        510 PMI(J,I)=PMITAB(J,I,MONTH)
            ACCP(I)=ACUPM(I,MONTH)
            ACCI(I)=ACUIM(I,MONTH)
            RPER(I)=REPERM(I,MONTH)
```

```
  520 RIMP(I)=REIMPM(I,MONTH)
  530 CONTINUE
      TEMPCF=TCF(MONTH)
C
C                        ZEROING OF VARIABLES
C
      DO 540 I=1,28
C          ZEROING OF THE FIRST 28 VARIABLES CONTAINED IN COMMON/LNDOUT/
  540 AR1OUT(I)=0.0
      PRTM=0.
      ROBTOM=0.
      INFTOM=0.
      DO 560 J=1,NQUAL
      DO 550 I=1,NLAND
      APOLP(I,J)=0.0
      APOLI(I,J)=0.0
  550 CONTINUE
      POLTCA(J)=0.0
  560 POLTC(J)=0.0
      DO 570 I=1,NLAND
      AERSN(I)=0.0
      AEIM(I)=0.0
  570 CONTINUE
      NOSIM=0
      NOS=0
      TEMPA=0.0
      DOA=0.0
      SEDTCA=0.0
      IX=2*MONTH
      IZ=IX-1
      RECOUT(1)=YEAR
            DYSTRT = 1
            IF (MOD(YEAR,4))  590, 580, 590
  580           GO TO (630,610,630,620,630,620,630,630,620,630,620,630),
     *MONTH
  590           GO TO (630,600,630,620,630,620,630,630,620,630,620,630),
     *MONTH
  600               DYEND = 28
                    GO TO 640
  610               DYEND = 29
                    GO TO 640
  620               DYEND = 30
                    GO TO 640
  630               DYEND = 31
C
  640       IMDEND=DYEND
            IF (YEAR .NE. BGNYR)  GO TO 650
            IF (MONTH .NE. BGNMON)  GO TO 650
            DYSTRT = BGNDAY
C
  650       IF (YEAR .NE. ENDYR)  GO TO 660
            IF (MONTH .NE. ENDMON)  GO TO 660
            DYEND = ENDDAY
C                                                   BEGIN DAILY LOOP
  660       DO 990  DAY=DYSTRT,DYEND
```

```
                    TIME = 0
                    RAINT = 0.0
                    EP = PETMUL*IEVAP(MONTH,DAY)/1000.
                    DO 670  I=1,INTRVL
                       IRAIN(I) = 0
                       RAIN(I) = 0.0
      670              CONTINUE
C
C
C                CHECK TO SEE IF SNOWMELT CALC'S WILL BE DONE - IF YES THEN
C                CALCULATE CONTINUOUS TEMP, WIND, RAD AND APPLY CORRES MULT
C                FACTORS
C
          IF (SNOW.LT.1) GO TO 790
          WINF=(1.0-F) + F*(.35-.03*KUGI)
C                                           WINF REDUCES WIND FOR FORESTED AREAS
C
C               /* KUGI IS INDEX TO UNDERGROWTH AND FOREST DENSITY,*/
C               /* WITH VALUES 0 TO 10 - WIND IN FOREST IS 35% OF  */
C               /* WIND IN OPEN WHEN KUGI=0, AND 5% WHEN KUGI=10 - */
C               /* WIND IS ASSUMED MEASURED AT 1-5 FT ABOVE GROUND */
C               /* OR SNOW SURFACE  */
C
                    WIND = IWIND(MONTH,DAY)
          TMIN = ITEMP(MONTH,DAY,2)
          DEWX = TMIN - 1.0*ELDIF
          RR = IRAD(MONTH,DAY)
C                                      DEWPT ASSUMED TO BE MIN TEMP AND USES
C                                      LAPSE RATE OF 1 DEGREE/1000 FT
C
C         CALCULATE CONTINUOUS TEMP, WIND, AND RAD
      680 CONTINUE
          TGRAD = 0.0
          DO 780 I=1,24
            IF (I-7)  740, 690, 700
      690   CHANGE = ITEMP(MONTH,DAY,1) - TEMPI
      700   IF (I-17)  740, 710, 740
C                        IMDEND IS LAST DAY OF PRESENT MONTH
      710   IF (DAY .NE. IMDEND)  CHANGE =ITEMP(MONTH,DAY+1,2) - TEMPI
            IF (MONTH-12)  730, 720, 730
      720   IF (DAY .EQ. IMDEND)  CHANGE = ITEMP(11,31,2) - TEMPI
            GO TO 740
      730   IF (DAY .EQ. IMDEND)  CHANGE = ITEMP(MONTH+1,1,2) - TEMPI
C
      740   IF (ABS(CHANGE)-0.001)  750, 750, 760
      750   TGRAD = 0.0
            GO TO 770
      760   TGRAD = GRAD(I)*CHANGE
      770   TEMPX(I) = TEMPI + TGRAD
            TEMPI = TEMPI + TGRAD
           IF (SNOW.LT.1) GO TO 780
            WINDX(I)  = WMUL*WIND*WINF*WINDIS(I)
            RAD(I)    = RMUL*RR*RADCON*RADDIS(I)
      780 CONTINUE
          IF (SNOW.LT.1) GO TO 950
```

```
C                                                    15-MIN PRECIP INPUT
  790           IF (PINT.EQ.1)   GO TO 850
                   J=0
  800              J=J+1
                   JK = J*12
                   JJ = JK - 11
                   READ (5,4020)  YR, MO, DY, CN, (IRAIN(I), I=JJ,JK)
                   IF (UNIT .EQ. -1) GO TO 820
                   DO 810 I=JJ,JK
                      IRAIN(I) = IRAIN(I)*3.937 + 0.5
  810                 CONTINUE
  820              IF (CN .EQ. 9)   J=9
                   YR = YR + 1900
                   IT = (YEAR-YR) + (MONTH-MO) + (DAY-DY) + (J-CN)
                   IF (IT .EQ. 0)   GO TO 830
                   WRITE (6,4000)  J, MONTH, DAY, YEAR, CN, MO, DY, YR
                   GO TO 1600
  830              IF (J.LT.8) GO TO 800
                DO 840  I=1,INTRVL
                   RAIN(I) = IRAIN(I)*K1/100.
                   RAINT = RAINT + RAIN(I)
  840              CONTINUE
                GO TO 920
C
C                                                    HOURLY PRECIP INPUT
  850              J=0
  860              J=J+1
                   JK = J*48
                   JJ = JK - 47
                   READ (5,4020)  YR, MO, DY, CN, (IRAIN(I), I=JJ,JK,4)
                   IF (UNIT .EQ. -1) GO TO 880
                   DO 870 I=JJ,JK,4
                      IRAIN(I)  =IRAIN(I)*3.937 + 0.5
  870                 CONTINUE
  880              IF (CN .EQ. 9)   J=9
                   YR = YR + 1900
                   IT = (YEAR-YR) + (MONTH-MO) + (DAY-DY) + (J-CN)
                   IF (IT .EQ. 0)   GO TO 890
                   WRITE (6,4000)  J, MONTH, DAY, YEAR, CN, MO, DY, YR
                   GO TO 1600
  890              IF(J.LT.2) GO TO 860
C
                DO 910  I=1,INTRVL,4
                   TEM = IRAIN(I)*(K1/100.)/4.
                   DO 900 K=1,4
  900              RAIN(I+4-K)=TEM
                   RAINT = RAINT + RAIN(I)
  910              CONTINUE
C
  920           IF (RAINT)  930, 930, 940
C
C  USE RAIN LOOP IF MOISTURE STORAGES ARE NOT EMPTY
C
  930  IF ((RESS .LT. 0.001).OR.(SRGXT .LT. 0.001))  GO TO 980
C
```

```
C                    RAIN LOOP
C
C      CONDITIONAL BRANCHING TO CALCULATE HOURLY TEMPERATURES
C
  940  IF (SNOW.LT.1) GO TO 680
  950  CONTINUE
C
C             CALCULATE COVER FUNCTION FOR THE PERVIOUS
C             AREAS WITHIN EACH LAND TYPE USE
C
      MTX=MONTH
      NTX=MONTH+1
      IF (NTX.GT.12) NTX=1
      DO 960 I=1,NLAND
      COVER(I)=COVMAT(I,MTX)+(FLOAT(DAY)/FLOAT(DYEND))*
     1        (COVMAT(I,NTX)-COVMAT(I,MTX))
  960 CONTINUE
               DO 970  I=1,INTRVL
                  TIME = TIME + 1
                  TF = 1
                  PR = RAIN(I)
C
                  IMIN = MOD(TIME,H)
                  IHR = (TIME - IMIN)/H
                  IMIN = TIMFAC*IMIN
                  IX = 2*MONTH
                  IZ = IX - 1
                 CALL LANDS
           IF (HYCAL.EQ.1) GO TO 970
                 CALL QUAL
  970 CONTINUE
                 NDSR=0
C
               GO TO 990
C
C                    NO RAIN LOOP
C
  980          TF = INTRVL
               PR = 0.0
               P3 = 0.0
                  RESB1 = 0.0
               IMIN = 00
               IHR = 24
               IX = 2*MONTH
               IZ = IX - 1
                NDSR=NDSR+1
                CALL LANDS
           IF (HYCAL.EQ.1) GO TO 990
                CALL QUAL
C                                                  END DAILY LOOP
  990          CONTINUE
C
C                           MONTHLY SUMMARY
C
      WRITE (6,4320) MNAM(IZ),MNAM(IX),YEAR
```

```
      UZSOT=UZS
      LZSOT=LZS
      SGWOT=SGW
      SCEPOT=SCEP
      RESSOT=RESS
      SRGXTO=SRGXT
      TWBALO=TWBAL
      TSNBOL=TSNBAL
      PACKOT=PACK
      IF (UNIT.EQ.-1) GO TO 1010
      DO 1000 I=1,28
C           CONVERSION TO METRIC UNITS OF THE FIRST 28 VARIABLES
C             CONTAINED IN COMMON/LNDOUT/
      AR1OUT(I)=AR1OUT(I)*MMPIN
 1000 CONTINUE
 1010 WRITE (6,4330) DEPW,ROSTOM,RINTOM,RITOM,BASTOM,RUTOM,RCHTOM,PRTOM
      IF (SNOW.LT.1) GO TO 1030
      COVR=100.
      IF (PACK.LT.IPACK) COVR=(PACK/IPACK)*100.
      IF (PACK.GT.0.01) GO TO 1020
      COVR=0.0
      SDEN=0.0
 1020 WRITE (6,4340) SUMSNM,PXSNM,MELRAM,RADMEM,CONMEM,CDRMEM,CRAINM,
     *                SGMM,SNEGMM,PACKOT,SDEN,COVR,SEVAPM
 1030 WRITE (6,4350) EPTOM,NEPTOM,UZSOT,LZSOT,SGWOT,SCEPOT,RESSOT,
     *                SRGXTO,TWBALO
      IF (SNOW.GT.0) WRITE (6,4360) TSNBOL
        IF (HYCAL.EQ.1) GO TO 1230
C
C           OUTPUT OF SEDIMENTS DEPOSIT ON GROUND AT MONTH'S END
C
      WRITE (6,4370) WHT,ARUN
       TEM1=0.0
       TEM2=0.0
       TEM3=0.0
       TEM4=0.0
      DO 1050 I=1,NLAND
      TEM=SRER(I)*(1-IMPK(I))+TS(I)*IMPK(I)
      WHFUN1=(AR(I)/AREA)*(1-IMPK(I))
      WHFUN2=(AR(I)/AREA)*IMPK(I)
      TEM1=TEM1+SRER(I)*WHFUN1
      TEM2=TEM2+TS(I)*WHFUN2
      TEM3=TEM3+WHFUN1
      TEM4=TEM4+WHFUN2
      IF (UNIT.GT.-1) GO TO 1040
      WRITE (6,4390) (LNDUSE(IK,I),IK=1,3),TEM,SRER(I),TS(I)
      GO TO 1050
 1040 TEM5=SRER(I)*2.24
      TEM6=TS(I)*2.24
      TEM=TEM*2.24
      WRITE (6,4390) (LNDUSE(IK,I),IK=1,3),TEM,TEM5,TEM6
 1050 CONTINUE
      IF (NLAND.EQ.1) GO TO 1070
      IF (TEM3.GT.0.0) TEM1=TEM1/TEM3
      IF (TEM3.LE.0.0) TEM1=0.0
```

```
      IF (TEM4.GT.0.0) TEM2=TEM2/TEM4
      IF (TEM4.LE.0.0) TEM2=0.0
      TEM=TEM1*(1-A)+TEM2*A
      IF (UNIT.LT.1) GO TO 1060
      TEM=TEM*2.24
      TEM1=TEM1*2.24
      TEM2=TEM2*2.24
 1060 WRITE (6,4380) TEM,TEM1,TEM2
C
C          OUTPUT MONTHLY SEDIMENTS LOSS FOR EACH LAND TYPE USE
C
 1070 WRITE (6,4400) WHT,WHGT,ARUN
      AERSNT=0.0
      AEIMT=0.0
      DO 1100 I=1,NLAND
      TEM=AEIM(I)+AERSN(I)
      IF (TEM.GT.0.0) GO TO 1080
      TEM1=0.0
      TEM2=0.0
      TEM3=0.0
      GO TO 1090
 1080 TEM1=TEM*2000./AR(I)
      TEM2=100.*AERSN(I)/TEM
      TEM3=100.*AEIM(I)/TEM
      IF (UNIT.LT.1) GO TO 1090
      TEM=TEM*.9072
      TEM1=TEM1*1.12
 1090 WRITE (6,4410) (LNDUSE(IK,I),IK=1,3),TEM,TEM1,TEM2,TEM3
      AERSNT=AERSNT+AERSN(I)
      AEIMT=AEIMT+AEIM(I)
 1100 CONTINUE
C
C          OUTPUT MONTHLY SEDIMENTS LOSS FOR THE ENTIRE WATERSHED
C
      TEM=AERSNT+AEIMT
      IF (TEM.GT.0.0) GO TO 1110
      TEM1=0.0
      TEM2=0.0
      TEM3=0.0
      GO TO 1120
 1110 TEM1=TEM*2000./AREA
      TEM2=100.*AERSNT/TEM
      TEM3=100.*AEIMT/TEM
      IF (UNIT.LT.1) GO TO 1120
      TEM=TEM*.9072
      TEM1=TEM1*1.12
 1120 WRITE (6,4470) TEM,TEM1,TEM2,TEM3
      WRITE (6,4420) WHGT ,WHGT,ARUN
C
C          OUTPUT MONTHLY WASHOFF FOR EACH OF THE ANALYZED POLLUTANTS
C
      DO 1180 J=1,NQUAL
      WRITE (6,4430) (QUALIN(I,J),I=1,3)
      APOLPT=0.0
      APOLIT=0.0
```

```
      DO 1150 I=1,NLAND
C
C          MONTHLY WASHOFF OF A GIVEN POLLUTANT FROM EACH LAND TYPE USE
C
      TEM=APOLP(I,J)+APOLI(I,J)
      IF (TEM.GT.0.0) GO TO 1130
      TEM1=0.0
      TEM2=0.0
      TEM3=0.0
      GO TO 1140
 1130 TEM1=TEM/AR(I)
      TEM2=100.*APOLP(I,J)/TEM
      TEM3=100.*APOLI(I,J)/TEM
      IF (UNIT.LT.1) GO TO 1140
      TEM=TEM*.454
      TEM1=TEM1/KGPHA
 1140 WRITE (6,4410) (LNDUSE(KK,I),KK=1,3),TEM,TEM1,TEM2,TEM3
      APOLPT=APOLPT+APOLP(I,J)
      APOLIT=APOLIT+APOLI(I,J)
 1150 CONTINUE
C
C         TOTAL MONTHLY WASHOFF OF A GIVEN POLLUTANT
C
      TEM=APOLPT+APOLIT
      IF (TEM.GT.0.0) GO TO 1160
      TEM1=0.0
      TEM2=0.0
      TEM3=0.0
      GO TO 1170
 1160 TEM1=TEM/AREA
      TEM2=100.*APOLPT/TEM
      TEM3=100.*APOLIT/TEM
      IF (UNIT.LT.1) GO TO 1170
      TEM=TEM*.454
      TEM1=TEM1/KGPHA
 1170 WRITE (6,4440) TEM,TEM1,TEM2,TEM3
 1180 CONTINUE
      TEMPAY=TEMPAY+TEMPA
      DOAY=DOAY+DOA
      SEDTCY=SEDTCY+SEDTCA
C
C          CALCULATE AND PRINT MONTHLY AVERAGES OF TEMPERATURE,
C          DISSOLVED OXYGEN,AND EACH OF THE ANALYSED POLLUTANT
C
      IF (NOSIM.LE.0) GO TO 1190
      TEMPA=TEMPA/NOSIM
      DOA=DOA/NOSIM
      SEDTCA=SEDTCA/NOSIM
 1190 TEMPO=TEMPA
      IF (UNIT.EQ.1) TEMPO=(TEMPO-32.)*5/9
      WRITE (6,4450) UTMP,TEMPO,DOA,SEDTCA
      DO 1210 J=1,NQUAL
      PLTCAY(J)=PLTCAY(J)+POLTCA(J)
      IF (NOSIM.LE.0) GO TO 1200
      POLTCA(J)=POLTCA(J)/NOSIM
```

```
 1200 WRITE (6,4460) (QUALIN(I,J),I=1,3),CUNIT(J),POLTCA(J)
 1210 CONTINUE
C
C              ACCUMULATION FOR YEARLY SUMMARIES
C
      DO 1220 I=1,NLAND
      AERSNY(I)=AERSNY(I)+AERSN(I)
      AEIMY(I)=AEIMY(I)+AEIM(I)
      DO 1220 J=1,NQUAL
      APOLPY(I,J)=APOLPY(I,J)+APOLP(I,J)
      APOLIY(I,J)=APOLIY(I,J)+APOLI(I,J)
 1220 CONTINUE
 1230 CONTINUE
      WRITE (6,4490) NOS
      NOSIY=NOSIY+NOSIM
      NOSY=NOSY+NOS
 1240 CONTINUE
C                                  END MONTHLY LOOP
C                              YEARLY SUMMARIES
C
      WRITE (6,4480) YEAR
      UZSMT=UZS
      LZSMT=LZS
      SGWMT=SGW
      SCEPT=SCEP
      RESST=RESS
      SRGXTT=SRGX
      TWBLMT=TWBAL
      TSNBOL=TSNBAL
      IF (UNIT.EQ.-1) GO TO 1260
      DO 1250 I=1,28
C         CONVERSION TO METRIC UNITS OF THE LAST 28 VARIABLES
C          CONTAINED IN COMMON/LNDOUT/
 1250 AR2OUT(I)=AR2OUT(I)*MMPIN
 1260 WRITE (6,4330) DEPW,ROSTOT,RINTOT,RITOT,BASTOT,RUTOT,RCHTOT,PRTOT
      IF (SNOW.LT.1) GO TO 1280
      COVR=100.
      IF (PACK.LT.IPACK) COVR=(PACK/IPACK)*100.
      IF (PACK.GT.0.01) GO TO 1270
      COVR=0.0
      SDEN=0.0
 1270 WRITE (6,4340) SUMSNY,PXSNY,MELRAY,RADMEY,CONMEY,CDRMEY,CRAINY,
     *               SGMY,SNEGMY,PACKOT,SDEN,COVR,SEVAPY
 1280 WRITE (6,4350) EPTOT,NEPTOT,UZSMT,LZSMT,SGWMT,SCEPT,RESST,
     *               SRGXTT,TWBLMT
      IF (SNOW.GT.0) WRITE (6,4360) TSNBOL
      IF (HYCAL.EQ.1) GO TO 1425
      WRITE (6,4400) WHT,WHT,ARUN
C
C         OUTPUT YEARLY SEDIMENTS LOSS FOR EACH LAND TYPE USE
C
      AERSNT=0.0
      AEIMT=0.0
      DO 1310 I=1,NLAND
      TEM=AEIMY(I)+AERSNY(I)
```

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      IF (TEM.GT.0.0) GO TO 1290
      TEM1=0.0
      TEM2=0.0
      TEM3=0.0
      GO TO 1300
 1290 TEM1=TEM/AR(I)
      TEM3=100.*AEIMY(I)/TEM
      TEM2=100.*AERSNY(I)/TEM
      IF (UNIT.LT.1) GO TO 1300
      TEM=TEM*.9072
      TEM1=TEM1/KGPHA
 1300 WRITE (6,4410) (LNDUSE(KK,I),KK=1,3),TEM,TEM1,TEM2,TEM3
      AERSNT=AERSNT+AERSNY(I)
      AEIMT=AEIMT+AEIMY(I)
 1310 CONTINUE
C
C           OUTPUT YEARLY SEDIMENTS LOSS FOR THE ENTIRE WATERSHED
C
      TEM=AERSNT+AEIMT
      IF (TEM.GT.0.0) GO TO 1320
      TEM1=0.0
      TEM2=0.0
      TEM3=0.0
      GO TO 1330
 1320 TEM1=TEM/AREA
      TEM2=100.*AERSNT/TEM
      TEM3=100.*AEIMT/TEM
      IF (UNIT.LT.1) GO TO 1330
      TEM=TEM*.9072
      TEM1=TEM1*2.24
 1330 WRITE (6,4470) TEM,TEM1,TEM2,TEM3
      WRITE (6,4420) WHGT,WHGT,ARUN
C
C           OUTPUT YEARLY WASHOFF FOR EACH OF THE ANALYZED POLLUTANTS
C
      DO 1390 J=1,NQUAL
      WRITE (6,4430) (QUALIN(I,J),I=1,3)
      APOLPT=0.0
      APOLIT=0.0
      DO 1360 I=1,NLAND
C
C           YEARLY WASHOFF OF A GIVEN POLLUTANT FROM EACH LAND TYPE USE
C
      TEM=APOLPY(I,J)+APOLIY(I,J)
      IF (TEM.GT.0.0) GO TO 1340
      TEM1=0.0
      TEM2=0.0
      TEM3=0.0
      GO TO 1350
 1340 TEM1=TEM/AR(I)
      TEM2=100.*APOLPY(I,J)/TEM
      TEM3=100.*APOLIY(I,J)/TEM
      IF (UNIT.LT.1) GO TO 1350
      TEM=TEM*.454
      TEM1=TEM1/KGPHA
```

```
 1350 WRITE (6,4410) (LNDUSE(KK,I),KK=1,3),TEM,TEM1,TEM2,TEM3
      APOLPT=APOLPT+APOLPY(I,J)
      APOLIT=APOLIT+APOLIY(I,J)
 1360 CONTINUE
C
C          TOTAL YEARLY WASHOFF OF A GIVEN POLLUTANT
C
      TEM=APOLPT+APOLIT
      IF (TEM.GT.0.0) GO TO 1370
      TEM1=0.0
      TEM2=0.0
      TEM3=0.0
      GO TO 1380
 1370 TEM1=TEM/AREA
      TEM2=100.*APOLPT/TEM
      TEM3=100.*APOLIT/TEM
      IF (UNIT.LT.1) GO TO 1380
      TEM=TEM*.454
      TEM1=TEM1/KGPHA
 1380 WRITE (6,4440) TEM,TEM1,TEM2,TEM3
 1390 CONTINUE
C
C           CALCULATE AND PRINT YEARLY AVERAGES OF TEMPERATURE,
C           DISSOLVED OXYGEN,AND EACH OF THE ANALYZED POLLUTANT
C
      IF (NOSIY.LE.0) GO TO 1400
      TEMPAY=TEMPAY/NOSIY
      DOAY=DOAY/NOSIY
      SEDTCY=SEDTCY/NOSIY
 1400 TEMPO=TEMPAY
      IF (UNIT.EQ.1) TEMPO=(TEMPO-32.)*5/9
      WRITE (6,4450) UTMP,TEMPO,DOAY,SEDTCY
      DO 1420 J=1,NQUAL
      IF (NOSIY.LE.0) GO TO 1410
      PLTCAY(J)= PLTCAY(J)/NOSIY
 1410 WRITE (6,4460) (QUALIN(I,J),I=1,3),CUNIT(J),PLTCAY(J)
 1420 CONTINUE
 1425 WRITE (6,4490) NOSY
C
C                            ZEROING OF VARIABLES
C
      DO 1430 I=1,28
C           ZEROING OF THE LAST 28 VARIABLES CONTAINED IN COMMON/LNDOUT/
 1430 AR2OUT(I)=0.0
      DO 1450 J=1,NQUAL
      DO 1440 I=1,5
      APOLPY(I,J)=0.0
 1440 APOLIY(I,J)=0.0
 1450 PLTCAY(J)=0.0
      DO 1460 I=1,5
      AERSNY(I)=0.0
 1460 AEIMY(I)=0.0
      NOSIY=0
      TEMPAY=0.0
      DOAY=0.0
```

```
C
C        SUMMARY OF STORMS' CHARACTERISTICS
C
         NV=(NQUAL+1)*4
         IF (HYCAL.EQ.1) NV=2
         IF (NOSY.LT.2.OR.NOSY.GT.200) GO TO 1560
C
C        CLEAR OUTPUT VECTORS AND INITIALIZE VMIN AND VMAX
C
         DO 1470 K=1,NV
         TOTAL(K)=0.0
         SD(K)=0.0
         VMIN(K)=1.0E75
    1470 VMAX(K)=-1.0E75
C
C       CALCULATE MEANS, ST.DEV'S,MAXIMA, AND MINIMA
C
         DO 1520 I=1,NOSY
         DO 1520 K=1,NV
         TOTAL (K)=TOTAL(K)+STMCH(I,K)
         IF (STMCH(I,K)-VMIN(K)) 1480,1490,1490
    1480 VMIN(K)=STMCH(I,K)
    1490 IF (STMCH(I,K)-VMAX(K)) 1510,1510,1500
    1500 VMAX(K)=STMCH(I,K)
    1510 SD(K)=SD(K)+STMCH(I,K)*STMCH(I,K)
    1520 CONTINUE
         DO 1530 K=1,NV
         RANGE(K)=VMAX(K)-VMIN(K)
         AVER(K)=TOTAL(K)/NOSY
         SD(K)=SQRT(ABS((SD(K)-TOTAL(K)*TOTAL(K)/NOSY)/(NOSY-1)))
    1530 CONTINUE
C
C        PRINT STORM CHARACTERISTICS
C
         IF (HYCAL.NE.1) GO TO 1540
         WRITE (6,4500)
         WRITE (6,4580) DEPW,AVER(1),SD(1),VMAX(1),VMIN(1),RANGE(1)
         WRITE (6,4590) UFL,AVER(2),SD(2),VMAX(2),VMIN(2),RANGE(2)
         GO TO 1570
    1540 WRITE (6,4500)
         WRITE (6,4510)
         WRITE (6,4530) WHT,AVER(1),SD(1),VMAX(1),VMIN(1),RANGE(1)
         WRITE (6,4540) WHGT,AVER(2),SD(2),VMAX(2),VMIN(2),RANGE(2)
         WRITE (6,4545) AVER(3),SD(3),VMAX(3),VMIN(3),RANGE(3)
         WRITE (6,4555) AVER(4),SD(4),VMAX(4),VMIN(4),RANGE(4)
         DO 1550 J=1,NQUAL
         WRITE (6,4430) (QUALIN(I,J),I=1,3)
         K=J*4+1
         WRITE (6,4530) WHT,AVER(K),SD(K),VMAX(K),VMIN(K),RANGE(K)
         K=K+1
         WRITE (6,4540) WHGT,AVER(K),SD(K),VMAX(K),VMIN(K),RANGE(K)
         K=K+1
         WRITE (6,4550) CUNIT(J),AVER(K),SD(K),VMAX(K),VMIN(K),RANGE(K)
         K=K+1
         WRITE (6,4560) CUNIT(J),AVER(K),SD(K),VMAX(K),VMIN(K),RANGE(K)
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 1550 CONTINUE
      GO TO 1570
 1560 WRITE (6,4570)
      IF (NOSY.EQ.0) GO TO 1590
 1570 DO 1580 I=1,NOSY
      DO 1580 K=1,NV
 1580 STMCH(I,K)=0.0
      NOSY=0
C                                     END OF YEARLY LOOP
 1590    CONTINUE
C
 1600 CONTINUE
C
C                        FORMAT STATEMENTS
C
 4000 FORMAT ('1','*****ERROR*****  INCORRECT INPUT DATA!   DESIRED ',
     *   'CARD ',I1,' FOR ',I2,'/',I2,'/',I4,'; READ CARD ',I1,' FOR ',
     *   I2,'/',I2,'/',I4)
 4010 FORMAT ('0')
 4020 FORMAT (1X,3I2,I1,12I6)
 4040 FORMAT (8X,24I3)
 4050 FORMAT (8X,12I6)
 4060 FORMAT (3A4,2X,A4 )
 4070 FORMAT ('1',9(/),45X,'NONPOINT SOURCE POLLUTANT LOADING MODEL',
     1        /,44X,42('='),10(/))
 4080 FORMAT (' ',1X,'WATERSHED CHARACTERISTICS :',///,6X,'NAME',8X,
     1       3A8,/,18X,3A8,//,6X,'TOTAL AREA (',A4,')',8X,F9.2,/)
 4090 FORMAT (9X,'LAND USE',5X,'% OF TOTAL',6X,'AREA (',A4,'S)',6X,
     1       'PERVIOUS (',A4,'S)',3X,'IMPERVIOUS (',A4,'S)',3X,
     2       'IMPERVIOUS (%)',/)
 4100 FORMAT (' ',7X,3A4,5X,F5.1,4(10X,F9.2))
 4110 FORMAT (/,6X,'FRACTION OF IMPERVIOUS AREA',2X,F5.2)
 4120 FORMAT ('0',8X,'**WARNING**',3X,'CHECK IF THE LAND TYPES AREAS ',
     1        'ARE CORRECT')
 4130 FORMAT (5(/),' ',1X,'SIMULATION CHARACTERISTICS :',///,6X,
     1       'TYPE OF RUN',10X,4A8,/,5X,'DATE SIMULATION BEGINS',
     2       13X,2A4,2X,I2,', ',I4,/,6X,'DATE SIMULATION ENDS',15X,
     3       2A4,2X,I2,', ',I4,/,6X,'INPUT PRECIPITATION TIME INTERVAL',
     4       9X,I3,1X,'MINUTES',/,6X,'SIMULATION TIME INTERVAL',19X,I2,
     5       1X,'MINUTES',/,6X,'IS SNOWMELT CONSIDERED ?',26X,A4,/,
     6       6X,'INPUT UNITS',34X,1A8,/,6X,'OUTPUT UNITS',33X,1A8,/,6X,
     7       'MINIMUM FLOW FOR OUTPUT PER INTERVAL (',A4,')',1X,F9.4,
     8       /,6X,'NUMBER OF QUALITY INDICATORS ANALYZED',14X,I2,
     9       /,6X,'THE ANALYZED QUALITY INDICATORS',4X,
     X       'SEDIMENTS,DO,TEMP,',/,5(46X,3A4,',',/))
 4140 FORMAT (5(/),2X,'SUMMARY OF INPUT PARAMETERS :',///,6X,
     1        'LANDS',13X,'INTER =',F7.3,4X,'IRC    =',F7.3,4X,
     2        'INFIL =',F7.3,/,24X,'NN     =',F7.3,4X,'L      =',
     3       F7.3,4X,'SS     =',F7.3,/,24X,'NNI    =',F7.3,4X,
     4       'LI     =',F7.3,4X,'SSI    =',F7.3,/,24X,'K1     =',F7.3,
     5       4X,'PETMUL=',F7.3,4X,'K3     =',F7.3,/,24X,'EPXM   =',
     6       F7.3,4X,'K24L  =',F7.3,4X,'KK24   =',F7.3,/,24X,
     7       'UZSN  =',F7.3,4X,'LZSN  =',F7.3)
 4150 FORMAT (/,6X,'SNOW',14X,'RADCON=',F7.3,4X,'CCFAC =',F7.3,4X,
     1        'EVAPSN=',F7.3,/24X,'MELEV =',F7.3,4X,'ELDIF =',F7.3,4X,
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     2          'TSNOW =',F7.3,/,24X,'MPACK =',F7.3,4X,'DGM   =',F7.3,
     3          4X,'WC    =',F7.3,/,24X,'IDNS  =',F7.3,4X,'SCF   =',F7.3,
     4          4X,'WMUL  =',F7.3,/,24X,'RMUL  =',F7.3,4X,'F     =',
     5          F7.3,4X,'KUGI  =',F7.3,/)
4160 FORMAT (/,6X,'QUAL   ',12X,'JRER  =',F7.3,4X,'KRER  =',F7.3,/,
     1          24X,'JSER  =',F7.3,4X,'KSER  =',F7.3,/,
     2          24X,'JEIM  =',F7.3,4X,'KEIM  =',F7.3,/)
4170 FORMAT (//,6X,'MONTHLY DISTRIBUTION',7X,11(A4,4X),A4,//,6X,
     1      'TEMP CORRECTION FACTOR',1X,12(2X,F6.2),///,7X,
     2      '- PERVIOUS LANDS -',///,6X,'LAND COVER-',3A4,1X,12(1X,F7.3))
4180 FORMAT (17X,3A4,1X,12(1X,F7.3))
4190 FORMAT (/,6X,'ACCUMULATION RATES')
4200 FORMAT (/,6X,'REMOVAL RATES')
4210 FORMAT (/,6X,'POTENCY FACTORS FOR',1X,3A4)
4220 FORMAT (//,6X,'-IMPERVIOUS LANDS-',/)
4230 FORMAT (24X,3A4,6X,'ACUP  =',F7.3,4X,'ACUI  =',F7.3)
4240 FORMAT (24X,3A4,6X,'RPER  =',F7.3,4X,'RIMP  =',F7.3)
4250 FORMAT (//,6X,'POTENCY FACTORS FOR PERVIOUS AREAS',5X,5(3A4,3X),/)
4260 FORMAT (24X,3A4,8X,5(F8.3,7X))
4270 FORMAT (//,6X,'POTENCY FACTORS FOR IMPERVIOUS AREAS',5(3X,3A4),/)
4280 FORMAT (5(/),2X,'INITIAL CONDITIONS :',3(/),6X,'LANDS',13X,
     1          'UZS   =',F7.3,4X,'LZS   =',F7.3,4X,'SGW   =',F7.3,/)
4290 FORMAT (6X,'SNOW',14X,'PACK  =',F7.3,4X,'DEPTH =',F7.3,/)
4300 FORMAT (6X,'QUAL',14X,3A4,6X,'TS   =',F9.3,4X,'SRER  =',F9.3)
4310 FORMAT (24X,3A4,6X,'TS   =',F9.3,4X,'SRER  =',F9.3)
4320 FORMAT ('1',25X,'SUMMARY FOR MONTH OF ',2A4,1X,I4,/,
     1          25X,35('='),//,35X,'TOTAL')
4330 FORMAT ('0',8X,'WATER,  ',A4,//,11X,'RUNOFF',/,14X,
     1          'OVERLAND FLOW',5X,F9.3,/,14X,'INTERFLOW',9X,F9.3,
     2          /,14X,'IMPERVIOUS',8X,F9.3,/,14X,'BASE FLOW',9X,
     3          F9.3,/,14X,'TOTAL',13X,F9.3,//,11X,
     4          'GRDWATER RECHARGE',4X,F9.3,//,11X,'PRECIPITATION',
     5          8X,F9.3)
4340 FORMAT (' ',13X,'SNOW',14X,F9.3,/,14X,'RAIN ON SNOW',6X,
     1          F9.3,/,14X,'MELT & RAIN',7X,F9.3,//,11X,'MELT',
     2          /,14X,'RADIATION',9X,F9.3,/,14X,'CONVECTION',8X,
     3          F9.3,/,14X,'CONDENSATION',6X,F9.3,/,14X,'RAIN - MELT',
     4          7X,F9.3,/,14X,'GROUND-MELT',7X,F9.3,/,14X,
     5          'CUM-NEG-HEAT',6X,F9.3,//,11X,'SNOW-PACK',12X,F9.3,
     6          /,11X,'SNOW DENSITY',9X,F9.3,/,11X,'% SNOW COVER',
     7          9X,F9.3,//,11X,'SNOW EVAP',12X,F9.3)
4350 FORMAT ('0',11X,'EVAPOTRANSPIRATION',/,14X,'POTENIAL',10X,
     1          F9.3,/,14X,'NET',15X,F9.3,//,11X,'STORAGES',/,
     2          14X,'UPPER ZONE',8X,F9.3,/,14X,'LOWER ZONE',8X,F9.3,
     3          /,14X,'GROUNDWATER',7X,F9.3,/,14X,'INTERCEPTION',6X,
     4          F9.3,/,14X,'OVERLAND FLOW',5X,F9.3,/,14X,'INTERFLOW',
     5          9X,F9.3,//,11X,'WATER BALANCE',8X,F9.3)
4360 FORMAT (' ',10X,'SNOW BALANCE',9X,F9.3)
4370 FORMAT ('0',8X,'SEDIMENTS ACCUMULATION ,',A4,'/',A4,9X,
     1          'WEIGHTED MEAN',7X,'PERVIOUS',11X,'IMPERVIOUS',/)
4380 FORMAT (11X,'WEIGHTED MEAN',27X,F10.3,3(10X,F10.3))
4390 FORMAT (' ',8X,3A4,29X,F11.3,3(9X,F11.3))
4400 FORMAT ('0',8X,'SEDIMENTS LOSS, ',11X,'TOTAL (',A4,')',3X,
     1      'TOTAL (',A4,'/',A4,')',3X,'PERVIOUS (%)',7X,'IMPERVIOUS (%)')
4410 FORMAT (' ',8X,3A4,9X,F11.3,3(5X,F15.3))
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      4420 FORMAT ('0',8X,'POLLUTANT WASHOFF, ',8X,'TOTAL (',A4,')',3X,
          1     'TOTAL (',A4,'/',A4,')',3X,'PERVIOUS (%)',7X,'IMPERVIOUS (%)')
      4430 FORMAT ('0', 9X,'WASHOFF OF ',3A4)
      4440 FORMAT (' ',10X,'TOTAL WASHOFF',5X,F11.3,3(9X,F11.3))
      4450 FORMAT ('0',8X,'STORM WATER QUALITY - AVERAGES',//,
          1         11X,'TEMPERATURE ',A4,6X,F7.2,//,11X,
          2         'DISSOLVED OXYGEN (PPM)',1X,F7.3,//,12X,
          3         'SEDIMENTS    (GM/L)',F11.3)
      4460 FORMAT (' ',11X,3A4,'(',A4,')',F11.3)
      4470 FORMAT (' ',10X,'TOTAL LOSS',10X,F10.3,3(10X,F10.3))
      4480 FORMAT ('1',25X,'SUMMARY FOR ',I4,/,25X,16('_'),//,35X,'TOTAL')
      4490 FORMAT ('0',8X,'NO. OF STORMS',14X,I3)
      4500 FORMAT ('0',8X,'SUMMARY OF STORMS'' CHARACTERISTICS',4X,
          1         'AVERAGE'.8X,'ST.DEV.',9X,'MAXIMA',9X,'MINIMA',
          2       9X,'RANGE',//)
      4510 FORMAT (11X,'SEDIMENTS LOSS')
      4520 FORMAT (3A8/3A8)
      4530 FORMAT (/,14X,'TOTAL WASHOFF (',A4,')',4X,5(5X,F10.3))
      4540 FORMAT (14X,'MAX WASHOFF (',A4,'/15MIN)',5X,F10.3,
          1          4(5X,F10.3))
      4545 FORMAT (14X,'MEAN CONCENTRATION (GM/L)',4X,F10.3,4(5X,F10.3))
      4550 FORMAT (14X,'MEAN CONCENTRATION (',A4,')',4X,F10.3,4(5X,F10.3))
      4555 FORMAT (14X,'MAX CONCENTRATION (GM/L)',5X,F10.3,4(5X,F10.3 ))
      4560 FORMAT (14X,'MAX CONCENTRATION (',A4,')',5X,F10.3,4(5X,F10.3 ))
      4570 FORMAT ('0',8X,'**WARNING**',3X,
          1          'SUMMARY OF STORM CHARACTERISTICS NOT PRINTED',
          2          /,22X,'NUMBER OF STORMS LESS THAN 2 OR MORE THAN 200',
          3          ' - CHECK YOUR HYMIN PARAMETER')
      4580 FORMAT (/,14X,'TOTAL RUNOFF (',A4,')',5X,5(5X,F10.3))
      4590 FORMAT (14X,'MAX RUNOFF (',A4,')',12X,F10.3,
          1          4(5X,F10.3))
C
            STOP
            END
            BLOCK DATA
C
C
C                         BLOCK DATA TO INITIALIZE VARIABLES
C
C
C
            IMPLICIT  REAL(L)
C
            DIMENSION MNAM(24),RAD(24),TEMPX(24),WINDX(24),RAIN(96),
          1            GRAD(24),RADDIS(24),WINDIS(24)
C
            COMMON /ALL/ RU,HYMIN,HYCAL,DPST,UNIT,TIMFAC,LZS,AREA,RESB,SFLAG,
          1              RESB1,ROSB,SRGX,INTF,RGX,RUZB,UZSB,PERCB,RIB,P3,TF,
          2              KGPLB,LAST,PREV,TEMPX,IHR,IHRR,PR,RUI,A,PA,GWF,NOSY,
          3              SRER(5),TS(5),LNDUSE(3,5),AR(5),QUALIN(3,5),NOSI,NOS,
          4              NOSIM,UFL,UTMP,UNT1(2,2),UNT2(2,2),UNT3(2,2),WHGT,
          5              WHT,DEPW,ROSBI,RESBI,RESBI1,ARUN,LMTS(5),IMPK(5),
          6              NLAND,NQUAL,STMCH(200,24),RECOUT(5),FLOUT,SCALEF(5),
          7              SNOW,PACK,IPACK
C
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      COMMON /LAND/DAY,PRTM,IMIN,IX,TWBAL,SGW,GWS,KV,LIRC4,LKK4,ALTR(9),
     1             UZS,I7,UZSN,LZSN,INFIL,INTER,SGW1,DEC,DECI,TIT(13),
     2             K24L,KK24,K24EL,EP,IFS,K3,EPXM,RESS1,RESS,SCEP,IRC,
     3             SRGXT1,MMPIN,KGPHA,METOPT,CCFAC,SCEP1,SRGXT,RAIN,SRC,
     4             SCF,IDNS,F,DGM,WC,MPACK,EVAPSN,MELEV,TSNOW,PETMIN,
     5             DEWX,DEPTH,MONTH,TMIN,PETMAX,ELDIF,SDEN,WINDX,INFTOM,
     6             TSNBAL,ROBTOM,ROBTOT,RXB,ROITOM,ROITOT,YEAR,CUNIT(7),
     7             INFTOT,MNAM,RAD,SRCI,FORM(42)
C
      COMMON /QLS/ WSNAME(6),KRER,JRER,KSER,JSER,TEMPCF,COVMAT(5,12),
     1             KEIM,JEIM,NDSR,ARP(5),ARI(5),ACCP(5),ACCI(5),RPER(5),
     2             PMP(5,5),PMI(5,5),QSNOW,SNOWY,SEDTM,SEDTY,SEDTCA,
     3             ACPOLP(5,5),ACERSN(5),APOLP(5,5),AERSN(5),COVEP(5),
     4             APOLI(5,5),ACEIM(5),AEIM(5),POLTM(5),POLTY(5),
     5             TEMPA,DOA,POLTCA(5),AERSNY(5),AEIMY(5),APOLPY(5,5),
     6             APOLIY(5,5),POLTC(5),PLTCAY(5),ACPOLI(5,5),RIMP(5)
C
      COMMON /LNDOUT/ ROSTOM,RINTOM,RITOM,RUTOM,BASTOM,RCHTOM,PRTOM,
     1                SUMSNM,PXSNM,MELRAM,RADMEM,CONMEM,CDRMEM,
     2                CRAINM,SGMM,SNEGMM,PACKOT,SEVAPM,EPTOM,NEPTOM,
     3                UZSOT,LZSOT,SGWOT,SCEPOT,RESSOT,SRGXTO,TWBALO,
     4                TSNBOL,ROSTOT,RINTOT,RITOT,RUTOT,BASTOT,RCHTOT,
     5                PRTOT,SUMSNY,PXSNY,MELRAY,RADMEY,CONMEY,CDRMEY,
     6                CRAINY,SGMY,SNEGMY,PACK1,SEVAPY,EPTOT,NEPTOT,
     7                UZSMT,LZSMT,SGWMT,SCEPT,RESST,SRGXTT,TWBLMT
C
      COMMON /STS/ ACPOLT(5),PLTMX(5),POLTSC(5),PLTMXC(5),
     1             ACSEDT,SEDMX,SEDTSC,SEDMXC,TOTRUN,PEAKRU
C
      COMMON /INTM/ RTYPE(4,4),UTYPE(2),GRAD,RADDIS,WINDIS,ICS,OFS,
     1              TEMPAY,DOAY,NOSIY,INTRVL,WMUL,NN,L,SS,NNI,LI,SSI,
     2              RMUL,KUGI,SEDTCY,REPERV(12),REIMPV(12),ACUPV(12),
     3              ACUIV(12),PMPMAT(12,5),PMIMAT(12,5),PMPVEC(5),
     4              PMIVEC(5),ACUI,ACUP,REIMP,REPER,PRINTR
C
      INTEGER  UNIT , LMTS, RECOUT, SFLAG, PRINTR
C
      LOGICAL LAST, PREV
C
      REAL*8  WSNAME,RTYPE,UTYPE
      REAL  JRER, KRER, JSER, KSER,KEIM,JEIM
      REAL  LZSN, IRC, NN, L, LZS, KV, K24L, KK24, INFIL, INTER
      REAL  IFS, K24EL, K3, NEPTOM, NEPTOT, ICS, NNI, KUGI
      REAL  INFTOM, INFTOT, INTF
      REAL  MMPIN, METOPT, KGPLB, KGPHA
      REAL  STU, STL ,IMPK
      REAL  MELRAM, MELRAY
C
      DATA  LAST/.FALSE./, PREV/.FALSE./
      DATA  PRTOT/0.0/
      DATA  PRTOM,PRTM/2*0.0/
      DATA  RUTOM, ROSTOM, RITOM, RINTOM, NEPTOM/5*0.0/
      DATA  RUTOT, ROSTOT, RITOT, RINTOT, NEPTOT/5*0.0/
      DATA  ROBTOM, ROBTOT, INFTOM, INFTOT, ROITOM, ROITOT/6*0.0/
      DATA  TWBAL, RESB, RESBI, ROSBI, RESBI1,SRGX, INTF/7*0.0/
```

```
      DATA  RESB1, BASTOM, RCHTOM, BASTOT, RCHTOT/5*0.0/
      DATA  EPTOM, EPTOT/2*0.0/
      DATA  PR, P3, RXB, RGX, RUZB, UZSB, PERCB, DPST/8*0.0/
      DATA  TIMFAC, UZSN, LZSN, INFIL, INTER, IRC/6*0.0/
      DATA  A, UZS, LZS, SGW, GWS, KV, K24L, K24EL, KK24/9*0.0/
      DATA  IFS, K3, EPXM/3*0.0/
      DATA  PETMIN,PETMAX/35.,40./
      DATA  TOTRUN,PEAKRU,ACSEDT,SEDMX,SEDTSC,SEDMXC/6*0.0/
      DATA  ACPOLT,PLTMX,POLTSC,PLTMXC/20*0.0/
      DATA  MNAM/' JAN','UARY','FEBR','UARY',' MAR','CH  ',' APR',
     *      'IL  ',' MAY','    ',' JUN','E   ',' JUL','Y   ',' AUG',
     *      'UST ','SEPT','MBER',' OCT','OBER','NOVE','MBER','DECE',
     *      'MBER'/
      DATA  MMPIN/25.4/, METOPT/0.9072/, KGPLB/0.4536/, KGPHA/0.892/
      DATA SUMSNM, PXSNM, MELRAM, RADMEM, CDRMEM, CRAINM,PACK,DEPTH,
     *       CONMEM, SGMM, SNEGMM, SEVAPM, SUMSNY, PXSNY, MELPAY,
     *       RADMEY, CDRMEY, CONMEY, CRAINY, SGMY, SNEGMY, SEVAPY,
     *       TSNBAL/23*0.0/
      DATA  INTRVL,PRINTR/15,15/,  WMUL,RMUL,KUGI,SFLAG/1.0,1.0,0.0,0/
      DATA  ICS, OFS/2*0.0/
      DATA GRAD/0.04,0.04,0.03,0.02,
     *0.02,0.02,0.02,0.06,0.14,0.18,0.20,0.17,0.13,0.06,0.03,0.01,0.05,
     *0.07,0.10,0.13,0.15,0.13,0.12,0.08/
      DATA RADDIS/6*0.0,0.019,
     *0.041,0.067,0.088,0.102,0.110,0.110,0.110,0.105,0.095,0.081,0.055,
     *0.017,5*0.0/
      DATA WINDIS/7*0.034,0.035,
     *0.037,0.041,0.046,0.050,0.053,0.054,0.058,0.057,0.056,0.050,0.043,
     *0.040,0.038,0.036,0.036,0.035/
      DATA NN,L,SS/3*0.0/, NNI,LI,SSI/3*0.0/
      DATA TEMPAY,DOAY,SEDTCA,SEDTCY/4*0.0/, NOSIY,NOSY/2*0/
      DATA CUNIT/5*4HGM/L,4HMG/L,4HGM/L/
      DATA FORM/4H(17X , 4H,A4, , 4H4X,A , 4H4,7X , 4H    ,4 , 4HX,'( ,
     *            4HLB)' , 4H,2X, ,4H'(GM , 4H/L)', 4H    ,4 , 4HX,'( ,
     *            4HLB)' , 4H,2X, ,4H'(GM , 4H/L)', 4H    ,4 , 4HX,'( ,
     *            4HLB)' , 4H,2X, ,4H'(GM , 4H/L)', 4H    ,4 , 4HX,'( ,
     *            4HLB)' , 4H,2X, ,4H'(GM , 4H/L)', 4H    ,4 , 4HX,'( ,
     *            4HLB)' , 4H,2X, ,4H'(GM , 4H/L)', 4H    ,4 , 4HX,'( ,
     *            4HLB)' , 4H,2X, ,4H'(GM , 4H/L)', 4H ,2( , 4H/))  /
      DATA ALTR/4H      , 4HKG)',
     *          4H'(MG, 4H( 21, 4H( 27, 4H( 41, 4H( 54, 4H( 63, 4H( 74 /
      DATA TIT/4H     , 4HX,'Q, 4H U A, 4H L I,  4H T Y, 4H    C,
     *    4H O N, 4H S T, 4H I T, 4H U E, 4H N T, 4H S', ,4H / )/
      DATA RTYPE/8H         ,'SEDIMENT','PRODUCTI','    PRODU',' HYDROL',
     *' AND QUA','ON (PRIN','CTION (O','OGIC CAL','LITY CAL','TER OUTP',
     *'UTPUT ON','IBRATION','IBRATION','UT ONLY)',' UNIT 4)'/
      DATA  UTYPE/'  METRIC',' ENGLISH'/
      DATA  COVMAT/60*0.0/, COVER/5*0.0/
      DATA  IMPK,SCALEF/5*0.,5*1./, NDSR,IHRR/2*0/
      DATA  PMP/25*0.0/, PMI/25*0.0/
      DATA QUALIN/' BOD',2*4H    ,' TDS',11*4H    /
      DATA QSNOW/' NO '/, SNOWY/'YES '/
      DATA JSER/0.0/, KRER/0.0/
      DATA JSER/0.0/, KSER/0.0/
      DATA  JEIM/0.0/, KEIM/0.0/
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      DATA UNT1/' KG ',' MM ',' LB ',' IN '/
      DATA  STMCH/4800*0.0/
      DATA UNT2/'  T ','CMS ','TONS','CFS '/
      DATA UNT3/'(C) ',' HA ','(F) ','ACRE'/
      DATA AERSN/5*0.0/, AEIM/5*0.0/, APOLP/25*0.0/, APOLI/25*0.0/
      DATA AERSNY/5*0.0/, AEIMY/5*0.0/, APOLPY/25*0.0/, APOLIY/25*0.0/
      DATA TEMPA,DOA/2*0.0/ ,NOSI,NOSIM,NOS/3*0/
      DATA POLTCA/5*0.0/,PLTCAY/5*0.0/
      DATA ACPOLP/25*0.0/, ACPOLI/25*0.0/
      DATA ACEIM,ACERSN/10*0.0/
      DATA  ACCP/5*0./, ACCI/5*0./, RIMP/5*0./, RPER/5*0./
      DATA  SRER/5*0./, TS/5*0./, LMTS/5*0/
      DATA  PMPVEC,PMIVEC,PMPMAT,PMIMAT/5*0.,5*0.,60*0.,60*0./
      DATA  ACUP,ACUI,ACUPV,ACUIV/0.,0.,12*0.,12*0./
      DATA  REPER,REIMP,REPERV,REIMPV/0.,0.,12*0.,12*0./
C
      END
       SUBROUTINE LANDS
C
C
C                               HSP LANDS
C
C
      IMPLICIT  REAL(L,K)
C
      DIMENSION EVDIST(24),LAPSE(24),SVP(40),SNOUT(24,16),STRBGN (4),
     1          MNAM(24),RAD(24),TEMPX(24),WINDX(24),RAIN(96),DUM1(5),
     2          DUM2(5)
C
      COMMON /ALL/ RU,HYMIN,HYCAL,DPST,UNIT,TIMFAC,LZS,AREA,RESB,SFLAG,
     1             RESB1,ROSB,SRGX,INTF,RGX,RUZB,UZSB,PERCB,RIB,P3,TF,
     2             KGPLB,LAST,PREV,TEMPK,IHR,IHRR,PR,RUI,A,PA,GWF,NOSY,
     3             SRER(5),TS(5),LNDUSE(3,5),AR(5),QUALIN(3,5),NOSI,NOS,
     4             NOSIM,UFL,UTMP,UNT1(2,2),UNT2(2,2),UNT3(2,2),WHGT,
     5             WHT,DEPW,ROSBI,RESBI,RESBI1,ARUN,LMTS(5),IMPK(5),
     6             NLAND,NQUAL,STMCH(200,24),RECOUT(5),FLOUT,SCALEF(5),
     7             SNOW,PACK,IPACK
C
      COMMON /LAND/DAY,PRTM,IMIN,IX,TWBAL,SGW,GWS,KV,LIRC4,LKK4,ALTR(9),
     1             UZS,IZ,UZSN,LZSN,INFIL,INTER,SGW1,DEC,DECI,TIT(13),
     2             K24L,KK24,K24EL,EP,IFS,K3,EPXM,RESS1,RESS,SCEP,IRC,
     3             SRGXT1,MMPIN,KGPHA,METOPT,CCFAC,SCEP1,SRGXT,RAIN,SRC,
     4             SCF,IDNS,F,DGM,WC,MPACK,EVAPSN,MELEV,TSNOW,PETMIN,
     5             DEWX,DEPTH,MONTH,TMIN,PETMAX,ELDIF,SDEN,WINDX,INFTOM,
     6             TSNBAL,ROBTOM,ROBTOT,RXB,ROITOM,ROITOT,YEAR,CUNIT(7),
     7             INFTOT,MNAM,RAD,SRCI,FORM(42)
C
      COMMON /LNDOUT/ ROSTOM,RINTOM,RITOM,RUTOM,BASTOM,RCHTOM,PRTOM,
     1                SUMSNM,PXSNM,MELRAM,RADMEM,CONMEM,CDRMEM,
     2                CRAINM,SGMM,SNEGMM,PACKOT,SEVAPM,EPTOM,NEPTOM,
     3                UZSOT,LZSOT,SGWOT,SCEPOT,RESSOT,SRGXTO,TWBALO,
     4                TSNBOL,ROSTOT,RINTOT,RITOT,RUTOT,BASTOT,RCHTOT,
     5                PRTOT,SUMSNY,PXSNY,MELRAY,RADMEY,CONMEY,CDRMEY,
     6                CRAINY,SGMY,SNEGMY,PACK1,SEVAPY,EPTOT,NEPTOT,
     7                UZSMT,LZSMT,SGWMT,SCEPT,RESST,SRGXTT,TWBLMT
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C
      COMMON /STS/ ACPOLT(5),PLTMX(5),POLTSC(5),PLTMXC(5),
     1              ACSEDT,SEDMX,SEDTSC,SEDMXC,TOTRUN,PEAKRU
C
      LOGICAL LAST, PREV
C
      INTEGER  TF,HYCAL, DAY, UNIT, SNOW, HRFLAG, H, SFLAG ,LMTS,STRBGN,
     1         RECOUT,YEAR
C
      REAL  INFIL, INTER, NN, INFLT, IRC, INTF, INFL
      REAL  IRC4, ICS, IFS, NEPTOM, NEPTOT
      REAL  INFTOM, INFTOT, QMETRC ,IMPK
      REAL  MMPIN, METOPT, KGPLB
      REAL  UZSMET, LZSMET, SGWMET, SCEPMT, RESSMT
      REAL  TWBLMT, SRGXTM, RESBMT, SRGXMT
      REAL IDNS, MPACK, MELEV, KUGI, NEGMLT, NEGMM
      REAL MELT, INDT, KCLD, IPACK, MELRAM, MELRAY
C
      DATA  PERC, INFLT, SBAS, HRFLAG/0.0,0.0,0.0,0/
      DATA  SNET1, SNET, SRCH/3*0.0/, NUMI/0/
      DATA  EOSINT, REPIN, EPIN1, AETR, KF/5*0.0/
      DATA  EVDIST/6*0.0,0.019,0.041,0.067,0.088,0.102,3*0.11,0.105,
     C      0.095,0.081,0.055,0.017,5*0.0/
      DATA SVP/10*1.005,1.01,1.01,1.015,1.02,
     *1.03,1.04,1.06,1.08,1.1,1.29,1.66,2.13,2.74,3.49,4.40,5.55,6.87,
     *8.36,10.09,12.19,14.63,17.51,20.85,24.79,29.32,34.61,40.67,47.68,
     *55.71,64.88/
      DATA LAPSE/6*3.5,3.7,4.0,4.1,
     *4.3,4.6,4.7,4.8,4.9,5.0,5.0,4.8,4.6,4.4,4.2,4.0,3.8,3.7,3.6/
      DATA  APR, AEPIN/2*0.0/
      DATA  AROSB, AINTF, AROSIT/3*0.0/
      DATA  ARU, ARUI, AROS, ARGXT, ASNET, ASBAS, ASRCH/7*0.0/
      DATA  SUMSN, INDT, KCLD, PXONSN, SEVAPT, RADME, CDRME, LIQW1,
     *      CONME, CRAIN, NEGMLT, SNEGM, NEGMM, LIQS,  LIQW, XICE,
     *      XLNMLT,SGM, SPX, WBAL, SEVAP/21*0.0/
      DATA  SNOUT/384*0.0/
      DATA  CLDF/-1.0/
C
C                     ZEROING OF VARIABLES
C
      LZS1 = LZS
      UZS1 = UZS
      NUMI = 0
      DPST = 0.0
      PACK1 = PACK
      LIQW1 = LIQW
      PRR = PR
C
      LNRAT=LZS/LZSN
      D3FV=(2.0*INFIL)/(LNRAT*LNRAT)
      D4F= (TIMFAC/60.)*D3FV
C                                             REDUCE INFILTRATION IF ICE EXISTS
C                                             AT THE BOTTOM OF THE PACK -
C                                            ATTEMPT TO CORRECT FOR FROZEN LAND
      IF (SNOW .LT. 1)  GO TO 20
```

```
            D4FX = (1.0 -XICE)
            IF (D4FX .LT. 0.1)  D4FX = 0.1
            D4F = D4F*D4FX
      C
         20 RATIO= INTER*EXP(0.693147*LNRAT)
            IF ((RATIO).LT.(1.0)) RATIO=1.0
            D4RA= D4F*RATIO
            H = TF/24
      C
      C                                          TF IS 1 FOR RAIN DAYS, AND 96
      C                                          OR 288 FOR NON-RAIN DAYS
      C
            IF (TF .GT. 2)  IHRR=0
      C
            DO 1480  III=1,TF
      C
            LNRAT = LZS/LZSN
            IF (TF .LT. 2)  GO TO 40
            NUMI =NUMI + 1
            IF (NUMI .EQ. H)  GO TO 30
            GO TO 40
         30 NUMI = 0
      C
         40 SBAS = 0.0
            SRCH = 0.0
            ROS = 0.0
            RU = 0.0
            GWF = 0.0
            RGXT = 0.0
            PERC = 0.0
            INFLT = 0.0
            RESS = 0.0
      C
      C   TIMFAC - TIME INTERVAL IN MINUTES
      C   L      - LENGTH OF OVERLAND SLOPE
      C   NN     - MANNING'S N FOR OVERLAND SLOPE
      C   A      - IMPERVIOUS AREA
      C   PA    - PERVIOUS AREA
      C
      C
      C
      C
      C PR IS INCOMING RAINFALL
      C P3 IS RAIN REACHING SURFACE(.00'S INCHES)
      C P4 IS TOTAL MOISTURE AVAILABLE( IN.)
      C RESS  IS OVERLAND FLOW STORAGE( IN.)
      C D4F IS 'B' IN OP. MANUAL
      C RATIO IS 'C' IN OP. MANUAL
      C EP -  DAILY EVAP ( IN.)
      C EPHR - HOURLY EVAP
      C EPIN - INTERVAL EVAP
      C EPXX - FACTOR FOR REDUCING EVAP FOR SNOW AND TEMP
      C
      C
      C
```

```
C
C      DETERMINE IF SNOWMELT IS TO BE DONE
C
    50 HRFLAG=0
       TEST = IMIN/TIMFAC
       IF (NUMI .EQ. 1)  HRFLAG = 1
       IF ((TEST .LE. 1.001).AND.(TEST .GE. 0.999)) HRFLAG = 1
C
C      HRFLAG=1 INDICATES BEGINNING OF THE HOUR
C
       IF (HRFLAG) 770, 770, 60
    60 IEND = 0
       IF (IHR-24)  70,80,70
    70 IHRR = IHR + 1
       GO TO 90
    80 IHRR = IHRR + 1
    90  EPHR = EVDIST(IHRR)*EP
        IF (EPHR.LE.(0.0001))  EPHR=0.0
        EPIN= EPHR
        EPIN1=EPIN
       IF (SNOW .EQ. 0) GO TO 770
       IF ((PACK .LE. 0.0).AND.(TMIN .GT. PETMAX))  GO TO 770
C                                ***********************************
C                                            BEGIN SNOWMELT
C                                ***********************************
       TSNOW1 = TSNOW + 1.
       SNTEMP = 32.
       SEVAP = 0.0
       SFLAG = 0
       PRHR=0.0
       EPXX = 1.0
       IKEND = 60./(TIMFAC)
       IPT = (IHRR-1)*IKEND
C                                 SUM PRECIP FOR THE HOUR
       PX=0.0
       DO 100 II = 1,IKEND
   100 PRHR = PRHR + RAIN(IPT+II)
C                                     CORRECT TEMP FOR ELEVATION DIFF
C                                     USING LAPSE RATE OF 3.5 DURING RAIN
C                                     PERIODS, AND AN HOURLY VARIATION IN
C                                     LAPSE RATE (LAPSE(I)) FOR DRY PERIOD
C
       LAPS = LAPSE(IHRR)
       IF (PRHR .GT. 0.05)  LAPS = 3.5
       TX = TEMPX(IHRR) - LAPS*ELDIF
C
C
C                                   REDUCE REG EVAP FOR SNOWMELT
C                                   CONDITIONS BASED ON PETMIN AND
C                                   PETMAX VALUES
C
       IF (PACK-IPACK) 120,120,110
   110 E1E=0.0
       PACKRA = 1.0
       GO TO 130
```

```
  120 PACKRA = PACK/IPACK
      E1E=1.0 - PACKRA
  130 EPXX = (1.0-F)*E1E + F
      IF (TX-PETMAX)  140,170,170
  140 IF (EPXX .GT. 0.5)  EPXX=0.5
C
C                                         REDUCE EVAP BY 50% IF TX IS BETWEEN
C                                         PETMIN AND PETMAX
  150 IF (TX-PETMIN)  160,170,170
  160 EPXX=0.0
C
C
  170 EPHR = EPHR*EPXX
      EPIN=EPIN*EPXX
      IEND=0
      IF ((TX .GT. TSNOW) .AND. (PRHR .GT. .02)) DEWX = TX
C
C     SET DEWPT TEMP EQUAL TO AIR TEMP WHEN RAINING
C     ON SNOW TO INCREASE SNOWMELT
C
      IF (DEWX .GT. TX) DEWX = TX
      SNTEMP = TSNOW + (TX-DEWX)*(0.12 + 0.008*TX)
C
C     RAIN/SNOW TEMP. DIVISION - SEE ANDERSON, WRR, VOL. 4, NO. 1,
C     FEB. 1968, P. 27, EG. 28
C
      IF (SNTEMP .GT. TSNOW1) SNTEMP = TSNOW1
      IF (TX -SNTEMP) 190, 180, 180
  180 IF  (PACK) 770, 770, 200
  190 SFLAG = 1
      IF ((PACK.LE.0.0).AND.(PRHR.LE.0.0)) GO TO 770
C
C          SKIP SNOWMELT IF BOTH PACK AND PRECIP ARE ZERO
C          FOR THE HOUR
C
  200 IEND = 1
C
C     SNOWMELT CALCULATIONS ARE DONE IF IT IS SNOWING, OR,
C     IF A SNOWPACK EXISTS
C
      PX = PRHR
      IF (PX)  250, 250, 210
C                                         KCLD IS INDEX TO CLOUD COVER
  210 KCLD = 35.
      IF (SFLAG) 260, 260, 220
C                                         SNOW IS FALLING
  220 PX = PX*SCF
      APR = APR+(SCF-1.0)*PRHR
      PRHR = PRHR*SCF
      SUMSN = SUMSN + PX
      DNS = IDNS
      IF (TX .GT. 0.0)  DNS = DNS + ((TX/100.)**2)
C
C     SNOW DENSITY WITH TEMP. - APPROX TO FIG. 4, PLATE B-1
C     SNOW HYDROLOGY  SEE ALSO ANDERSON, TR 36, P. 21
```

```
C
      PACK = PACK + PX
C
      IF (PACK-IPACK)  240,240,230
  230 IPACK = PACK
      IF (IPACK .GT. MPACK)  IPACK = MPACK
C
  240 DEPTH = DEPTH + (PX/DNS)
      IF (DEPTH .GT. 0.0) SDEN = PACK/DEPTH
      INDT = INDT - 1000*PX
      IF (INDT .LT. 0.0) INDT = 0.0
      PX = 0.0
      GO TO 260
  250 KCLD = KCLD - 1.
  260 IF (KCLD .LT. 0.0) KCLD = 0.0
      PACKRA = PACK/IPACK
      IF (PACK .GT. IPACK)  PACKRA = 1.0
C
  270 IF (PACK - 0.005)  280, 300, 300
C
C     IPACK IS AN INDEX TO AREAL COVERAGE OF THE SNOWPACK
C     FOR INITIAL STORMS IPACK = .1*MPACK SO THAT COMPLETE
C     AREAL COVERAGE RESULTS.  IF EXISTING PACK > .1 *MPACK THEN
C     IPACK IS SET EQUAL TO MPACK WHICH IS THE WATER EQUI. FOR
C     COMPLETE AREAL COVERAGE PACKRA IS THE FRACTION AREAL COVERAGE
C     AT ANY TIME.
C
  280 IPACK = 0.1*MPACK
      XICE = 0.0
      XLNMLT = 0.0
      NEGMLT = 0.0
      PX = PX + PACK + LIQW
      PACK = 0.0
      LIQW = 0.0
C
C              ZERO SNOWMELT OUTPUT ARRAY
C
      DO 290 I=1,24
      DO 290 MM=1,16
  290 SNOUT(I,MM)=0.0
      GO TO 760
  300 PXONSN = PXONSN + PX
      IF (DEPTH .GT. 0.0) SDEN = PACK/DEPTH
      IF (INDT .LT. 800.) INDT = INDT + 1.
C                          INDT IS INDEX TO ALBEDO
      MELT = 0.0
      IF (SDEN .LT. 0.55) DEPTH=DEPTH*(1.0 - 0.00002*(DEPTH*(.55-SDEN)))
C
C     EMPIRICAL RELATIONSHIP FOR SNOW COMPACTION
C
      IF (DEPTH .GT. 0.0) SDEN = PACK/DEPTH
      WIN = WINDX(IHRR)
C
C     HOURLY WIND VALUE
C
```

```
      LREF = (TX + 100.)/5
      LREF = IFIX(LREF)
      SVPP = SVP (LREF)
      ITX = IFIX(TX)
      SATVAP = SVPP +(MOD(ITX,5)/5)*(SVP(LREF + 1) - SVPP)
      LREF = (DEWX + 100.)/5
      LREF = IFIX(LREF)
      SVPP = SVP (LREF)
      IDEWX = IFIX(DEWX)
      VAPP = SVPP + (MOD(IDEWX,5)/5)*(SVP(LREF + 1) - SVPP)
C                         CALCULATION OF VAPOR PRESSURE AT AIRTEMP
C                         AND DEWPOINT
      IF (VAPP - 6.108)  320, 320, 310
  310 CNM = 8.59*(VAPP - 6.108)
      GO TO 330
  320 CNM = 0.0
      DUMMY=(VAPP-SATVAP)*PACKRA
      IF (VAPP .LT. SATVAP) SEVAP = EVAPSN*0.0002*WIN*DUMMY
      PACK = PACK + SEVAP
      SEVAPT = SEVAPT - SEVAP
C
C     CONDENSATION - CONVECTION MELT, EQ. T-29B, P.176, SNOW HYDROLOGY
C     CONV - CONVECTION, CONDS - CONDENSATION
C     SEVAP - EVAP FROM SNOW (NEGATIVE VALUE)
C
  330 CNV = C.0
      IF (TX .GT. 32.) CNV = (TX-32.)*(1.0 - 0.3*(MELEV/10000.))
      CCXC = CCFAC*.00026*WIN
C
C     .00026 = .00629/24, I.E. .00026 IS THE DAILY COEFFICIENT
C     (FROM SNOW HYDROLOGY) REDUCED TO HOURLY VALUES.
C
      CONV = CNV*CCXC
      CONDS = CNM*CCXC
C                              CLOUD COVER
C                              CLDF IS FRACTION OPEN SKY - MINIMUM VALUE 0.15
      IF ((IHRR.EQ.1).OR.(CLDF.LT.0.0)) CLDF = (1.0 - 0.085*(KCLD/3.5))
C                              ALBEDO
      IF (MONTH - 9)  340, 340, 360
  340 IF (MONTH - 4)  360, 350, 350
  350 ALBEDO = 0.8 - 0.1*(SQRT(INDT/24.))
      IF (ALBEDO .LT. 0.45)  ALBEDO = 0.45
      GO TO 370
  360 ALBEDO = 0.85 - 0.07*(SQRT(INDT/24.0))
      IF (ALBEDO.LT.0.6) ALBEDO=0.6
C                              SHORT WAVE RADIATION-RA - POSITIVE INCOMING
  370 RA = RAD(IHRR)*(1.0 -ALBEDO)*(1.0-F)
C                              LONG WAVE RADIATION - LW - POSITIVE INCOMING
      DEGHR = TX - 32.0
      IF (DEGHR)  390, 390, 380
  380 LW = F* 0.26*DEGHR + (1.0 - F)*(0.2*DEGHR - 6.6)
      GO TO 400
  390 LW = F*0.2*DEGHR + (1.0 - F)*(0.17*DEGHR - 6.6)
C
C                                 LW IS A LINEAR APPROX. TO CURVES IN
```

```
      C                            FIG. 6, PL 5-3, IN SNOW HYDROLOGY.  6.6
      C                            IS AVE BACK RADIATION LOST FROM THE SNOWPACK
      C                            IN OPEN AREAS, IN LANGLEYS/HR.
      C
      C                            CLOUD COVER CORRECTION
  400 IF (LW .LT. 0.0)  LW = LW*CLDF
      C
      C                            RAIN MELT
      RAINM = 0.0
      C
      C                                       RAINMELT IS OPERATIVE IF IT IS
      C                                       RAINING AND TEMP IS ABOVE 32 F
      C
      IF ((SFLAG .LT. 1).AND.(TX .GT. 32.))  RAINM = DEGHR*PX/144.
      C                            TOTAL MELT
      RM = (LW + RA)/203.2
      C                            203.2 LANGLEYS REQUIRED TO PRODUCE I INCH
      C                            RUNOFF FROM SNOW AT 32 DEGREES F
      IF (PACK - IPACK )  410, 430, 430
  410 RM = RM*PACKRA
      CONV = CONV*PACKRA
      CONDS = CONDS*PACKRA
      RAINM = RAINM*PACKRA
      IF (IHRR - 6)  430, 420, 430
  420 XLNEM = 0.01*(32.0 - TX)
      IF (XLNEM .GT. XLNMLT) XLNMLT = XLNEM
  430 RADME = RADME + RM
      CDRME = CDRME + CONDS
      CONME = CONME + CONV
      CRAIN = CRAIN + RAINM
      MELT = RM + CONV + CONDS + RAINM
      IF (MELT)  440, 470, 470
  440 NEGMM = 0.0
      IF (TX .LT. 32.) NEGMM = 0.00695*(PACK/2.0)*(32.0 - TX)
      C
      C                                       HALF OF PACK IS USED TO CALCULATE
      C                                       MAXIMUM NEGATIVE MELT
      C
      TP = 32.0 - (NEGMLT/(0.00695*PACK))
      C
      C     TP IS TEMP OF THE SNOWPACK
      C     0.00695 IS IN. MELT/IN. SNOW/DEGREE F
      C
      IF (TP - TX)  460, 460, 450
  450 GM = 0.0007*(TP - TX)
      NEGMLT = NEGMLT + GM
      SNEGM = SNEGM + GM
  460 IF (NEGMLT .GT. NEGMM)  NEGMLT = NEGMM
      MELT = 0.0
      C
      C                           MELTING PROCESS BALANCE
      C
  470 PXBY = (1.0 - PACKRA)*PX
      PX = PACKRA*PX
      C
```

```
C      PXBY IS FRACTION OF PRECIP FALLING ON BARE GROUND
C
       IF (MELT + PX)   650,650,480
C
C      SATISFY NEGMLT FROM PRECIP(RAIN) AND SNOWMELT
C
   480 IF (MELT - NEGMLT) 490, 500, 500
   490 NEGMLT = NEGMLT - MELT
       MELT = 0.0
       GO TO 510
   500 MELT = MELT - NEGMLT
       NEGMLT = 0.0
C
   510 IF (PX - NEGMLT)  520, 530, 530
   520 NEGMLT = NEGMLT - PX
       PACK = PACK + PX
       PX = 0.0
       GO TO 540
   530 PX = PX - NEGMLT
       PACK = PACK + NEGMLT
       NEGMLT = 0.0
C
   540 IF ((PX + MELT) .EQ. 0.0) GO TO  560
C
C      COMPARE SNOWMELT TO EXISTING SNOWPACK AND WATER CONTENT OF
C      THE PACK
C
       IF (MELT - PACK)  560, 560, 550
   550 MELT = PACK + LIQW
       DEPTH = 0.0
       PACK = 0.0
       LIQW = 0.0
       INDT = 0.0
       GO TO 590
   560 PACK = PACK - MELT
       IF (SDEN .GT. 0.0)  DEPTH = DEPTH - (MELT/SDEN)
       IF (PACK .GE. (0.9*DEPTH))  DEPTH = 1.11*PACK
       IF (PACK - 0.001)  570, 580, 580
   570 LIQW = LIQW + PACK
       PACK = 0.0
   580 LIQS = WC*PACK
       IF (SDEN .GT. 0.6) LIQS = WC*(3.0 - (3.33)*SDEN)*PACK
       IF (LIQS .LT. 0.0) LIQS = 0.0
C
C      COMPARE AVAILABLE MOISTURE WITH AVAILABLE STORAGE IN SNOWPACK
C      -LIQS
C
   590 IF ((LIQW + MELT + PX) - LIQS)  610, 610, 600
   600 PX = MELT + PX + LIQW - LIQS
       LIQW = LIQS
       GO TO 620
   610 LIQW = LIQW + MELT + PX
       PX = 0.0
   620 IF (PX - XLNMLT)  640, 640, 630
   630 PX = PX - XLNMLT
```

```
      PACK = PACK + XLNMLT
      XICE = XICE + XLNMLT
      XLNMLT = 0.0
      GO TO 650
  640 PACK = PACK + PX
      XICE = XICE + PX
      XLNMLT = XLNMLT - PX
      PX = 0.0
  650 IF (XICE .GT. PACK) XICE = PACK
C
C
C                                     END MELTING PROCESS BALANCE
C
  660 IF (DEPTH .GT. 0.0) SDEN = PACK/DEPTH
      IF (SDEN .LT. 0.1) SDEN = 0.1
C                                        GROUNDMELT
      IF (IHRR - 12)  700, 670, 700
  670 DGMM = DGM
      IF (TP .LT. 5.0)  TP = 5.0
      IF (TP .LT. 32.)  DGMM = DGMM - DGM*.03*(32.0 - TP)
      IF (PACK - DGMM)  690, 690, 680
  680 PX = PX + DGMM
      PACK = PACK - DGMM
      DEPTH = DEPTH - (DGMM/SDEN)
      SGM = SGM + DGMM
      GO TO 700
  690 PX = PACK + PX + LIQW
      SGM = SGM + PACK
      PACK = 0.0
      DEPTH = 0.0
      LIQW = 0.0
      NEGMLT = 0.0
  700 CONTINUE
      PX = PX + PXBY
      SPX = SPX + PX
C
C                                            MONTHLY SUMS
      SUMSNM = SUMSNM + SUMSN
      PXSNM  = PXSNM  + PXONSN
      MELRAM = MELRAM + SPX
      RADMEM = RADMEM + RADME
      CDRMEM = CDRMEM + CDRME
      CONMEM = CONMEM + CONME
      CRAINM = CRAINM + CRAIN
      SGMM   = SGMM   + SGM
      SNEGMM = SNEGMM + SNEGM
      SEVAPM = SEVAPM + SEVAPT
C
C                                            YEARLY SUMS
      SUMSNY = SUMSNY + SUMSN
      PXSNY  = PXSNY  + PXONSN
      MELRAY = MELRAY + SPX
      RADMEY = RADMEY + RADME
      CDRMEY = CDRMEY + CDRME
      CONMEY = CONMEY + CONME
```

```
            CRAINY = CRAINY + CRAIN
            SGMY   = SGMY   + SGM
            SNEGMY = SNEGMY + SNEGM
            SEVAPY = SEVAPY + SEVAPT
      C                                                ZERO HOURLY VALUES
            SUMSN = 0.0
            PXONSN = 0.0
            RADME = 0.0
            CDRME = 0.0
            CONME = 0.0
            CRAIN = 0.0
            SGM = 0.0
            SNEGM = 0.0
            SEVAPT = 0.0
            SPX = 0.0
      C                                   SNOWMELT OUTPUT
      C
            SNOUT(IHRR,1) = PACK
            SNOUT(IHRR,2) = DEPTH
            SNOUT(IHRR,3) = SDEN
            SNOUT(IHRR,4) = ALBEDO
            SNOUT(IHRR,5) = CLDF
            SNOUT(IHRR,6) = NEGMLT
            SNOUT(IHRR,7) = LIQW
            SNOUT(IHRR,8) = TX
            SNOUT(IHRR,9) = RA
            SNOUT(IHRR,10) = LW
            SNOUT(IHRR,11) = PX
            SNOUT(IHRR,12) = MELT
            SNOUT(IHRR,13) = CONV
            SNOUT(IHRR,14) = RAINM
            SNOUT(IHRR,15) = CONDS
            SNOUT(IHRR,16) = XICE
            IF (UNIT.LT.1.OR.HYCAL.GT.1) GO TO 730
      C
      C  CONVERSION TO METRIC SNOW OUTPUT
      C
               SNOUT(IHRR,1) = PACK*MMPIN
               SNOUT(IHRR,2) = DEPTH*MMPIN
               SNOUT(IHRR,6) = NEGMLT*MMPIN
               SNOUT(IHRR,7) = LIQW*MMPIN
               SNOUT(IHRR,8) = 0.556*(TX-32.0)
               DO 720 ISNOUT=11,16
                  SNOUT(IHRR,ISNOUT) = SNOUT(IHRR,ISNOUT)*MMPIN
        720    CONTINUE
      C
      C
      C
        730 IF (HYCAL.GT.1)  GO TO 760
            IF (IHRR .NE. 24)  GO TO 760
            WRITE (6,4020) MNAM(IZ),MNAM(IX),DAY
            WRITE(6,4000)
      C
            DO 750 I=1,24
            WRITE (6,4010) I,(SNOUT(I,MM),MM=1,16)
```

```
          DO 740 MM=1,16
      740 SNOUT(I,MM)=0.0
      750 CONTINUE
C
C
     4000 FORMAT('0','HOUR  PACK   DEPTH  SDEN  ALBEDO  CLDF  NEGMELT  LIQW
         *  TX     RA    LW    PX    MELT     CONV    RAINM   CONDS    ICE')
     4010 FORMAT(' ',I2,2X,F6.1,2X,F6.1,5(1X,F6.3),1X,F6.2,2(1X,F4.0),
         *5(1X,F7.4),2X,F5.2)
     4020 FORMAT ('0',25X,'SNOWMELT OUTPUT FOR',4X,A4,A4,2X,I2)
C
C                                CORRECT WATER BALANCE FOR SNOWMELT
C                                PACK AND SNOW EVAP
C
C                                PRR IS INCOMING PRECIP
C                                PX  IS MOISTURE TO THE LAND SURFACE
C                                SEVAP IS SNOW EVAP - NEGATIVE
      760 SNBAL = PRHR+SEVAP-PX-PACK+PACK1-LIQW+LIQW1
          IF ((SNBAL.LT.0.0001).AND.(SNBAL.GT.-0.0001))  SNBAL=0.0
          TSNBAL = TSNBAL + SNBAL
C
C
          PACK1 = PACK
          LIQW1 = LIQW
C                     **********************************
C                               END SNOWMELT
C                     **********************************
C                                              PX IS TOTAL MOISTURE INPUT TO
C                                              THE LAND SURFACE FROM PRECIP
C                                              AND SNOWMELT DURING THE HOUR
C
      770 IF (IEND .GT. 0) PR=PX*TIMFAC/60.
C                                           IEND>0 INDICATES SNOWMELT
C                                           OCCURRED DURING THE HOUR
C
C
C
C
C    * * *    INTERCEPTION  FUNC.     * * *
C
C
C EPXM - MAX. INTERCEPTION STORAGE
C SCEP - EXISTING INTER. STORAGE
C EPX  - AVAILABLE INTER. STORAGE
C RUI  - IMPERVIOUS RUNOFF DURING INTERVAL
C .
C
           EPX=EPXM-SCEP
           IF(EPX.LT.(0.0001))  EPX=0.0
           IF (PR-EPX)    790,780,780
      780  P3= PR-EPX
           SCEP = SCEP+EPX
           GO TO 800
      790  SCEP = SCEP+PR
           P3=0.0
```

```
            RU=0.0
            RUI=0.0
C
C ***    OVERLAND IMPERVIOUS FLOW ROUTING ***
C
C
C RXBI = VOLUME OF IMPERVIOUS OVERLAND FLOW ON SURFACE
C  ROSBI = VOLUME OF OVERLAND IMPERVIOUS FLOW TO STREAM
C  RESBI = VOLUME OF OVERLAND IMPERVIOUS Q REMAINING ON SURFACE
C
C
  800 IF (A) 810,810,820
  810 RUI=0.0
      GO TO 930
  820 RXBI=P3+RESBI
      IF (RXBI-0.001) 830,830,840
  830 RUI=RXBI*A
      RXBI=0.0
      ROSBI=RUI
      GO TO 930
  840 F1= RXBI-(RESBI)
      F3= (RESBI)+ RXBI
      IF (RXBI-(RESBI)) 860,860,850
  850 DE= DECI*((F1)**0.6)
      GO TO 870
  860 DE= (F3)/2.0
  870 IF (F3-(2.0*DE)) 890,890,880
  880 DE=(F3)/2.0
  890 IF ((F3)-(.005)) 900,900,910
  900 ROSBI= 0.0
      GO TO 920
  910    DUMV=(1.0+0.6*(F3/(2.0*DE))**3.)**1.67
      ROSBI=(TIMFAC/60.)*SRCI*((F3/2.)**1.67)*DUMV
      IF ((ROSBI).GT.(.95*RXBI)) ROSBI=.95*RXBI
  920 RESBI= RXBI-ROSBI
      RUI=ROSBI*A
  930 RU=RUI
C
C
C
C   * * *     INTERCEPTION EVAP      * * *
C
C
  940  IF ((NUMI .EQ. 0).AND.(IMIN .EQ. 0))  GO TO 950
       GO TO 1000
C
  950  IF  (SCEP)  1000,1000,960
  960  IF (SCEP-EPIN)  970,980,980
  970  EPIN = EPIN - SCEP
       SNET = SNET + SCEP
       SCEP = 0.0
       GO TO 1000
  980  SCEP=SCEP-EPIN
  990  SNET=SNET+EPIN
       EPIN = 0.0
```

```
C
C
C     ***  INFILTRATION FUNC.   ***
C  P4 IS TOTAL MOISTURE
C SHRD = SURFACE DETENTION AND INTERFLOW
C RXX = SURFACE DETENTION
C RGXX = INTERFLOW  COMPONENT
C  RGX = VOLUME TO INTER. DEPEN STOR.
C
C
 1000 P4 = P3 + RESB
      RESB1 = RESB
      IF (P4 - D4F) 1010,1010,1020
 1010 SHRD=(P4**2)/(2.0*D4F)
      GO TO 1030
 1020 SHRD= P4 - 0.5*D4F
      IF (P4 - D4RA) 1030,1030,1040
 1030 RXX = (P4**2)/(2.0*D4RA)
      GO TO 1050
 1040 RXX= P4 - 0.5*D4RA
 1050 RGXX  = SHRD-RXX
C
C
C   ***  UPPER ZONE FUNCTION ***
C
C PRE  - % SURFACE DETENTION TO OVERLAND FLOW
C UZSB -  UPPER ZONE STORAGE
C UZS  - TOTAL UPPER ZONE STORAGE
C RUZB - ADDITION TO U.Z. STORAGE DURING INTERVAL
C
      IF (UZSB.LT.0.0)  UZSB=0.0
      UZRA= UZSB/UZSN
      IF (UZRA.GT.6.0) GO TO 1060
      IF (UZRA.GT.2.0) GO TO 1070
      UZI= 2.0*ABS((UZRA/2.0)-1.0) +1.0
      PRE= (UZRA/2.0)*((1.0/(1.0+UZI))**UZI)
      GO TO 1080
 1060 PRE = 1.0
      GO TO 1080
 1070 UZI= (2.0*ABS(UZRA-2.0))+1.0
      PRE= 1.0-((1.0/(1.0+UZI))**UZI)
 1080 RXB= RXX* PRE
        RGX=RGXX*PRE
        RGXX=0.0
        RUZB=SHRD-RGX-RXB
        UZSB=UZSB+RUZB
C
        RIB = P4 - RXB
C
C
C
C   * * *      UPPER ZONE EVAP    * * *
C
C
C REPIN - ACCUM DAILY EVAP POT. FOR L.Z. AND GRDWATER, I.E
```

```
C          PORTION NOT SATISFIED FROM U.Z.
C
C
         IF ((NUMI .EQ. 0).AND.(IMIN .EQ. 0))   GO TO 1090
         GO TO 1150
C
 1090    IF (EPIN.LE.(0.0))   GO TO 1150
           EFFECT=1.0
           IF(UZRA-2.0)   1120,1120,1100
 1100      IF (UZSB-EPIN)   1140,1140,1110
 1110      UZSB=UZSB-EPIN
           RUZB= RUZB-EPIN
           SNET=SNET+PA*EPIN
           GO TO 1150
 1120      EFFECT= 0.5*UZRA
           IF (EFFECT.LT.(0.02))   EFFECT=0.02
           IF (UZSB-EPIN*EFFECT)   1140,1140,1130
 1130      UZSB=UZSB - (EPIN*EFFECT)
           RUZB= RUZB-(EPIN*EFFECT)
           EDIFF= (1.0-EFFECT)*EPIN
           REPIN=REPIN + EDIFF
           EDIFF=0.0
           SNET= SNET + (PA*EPIN*EFFECT)
           GO TO 1150
 1140      EDIFF= EPIN - UZSB
           REPIN= REPIN + EDIFF
           EDIFF=0.0
           SNET= SNET + PA*UZSB
           UZSB=0.0
           RUZB=0.0
C
C
C     * * * *    INTERFLOW FUNCTION * * *
C
C      SRGX - INTERFLOW DETENTION STORAGE
C      INTF - INTERFLOW LEAVING STORAGE
C      SRGXT - TOTAL INTERFLOW STORAGE
C      RGXT  - TOTAL INTERFLOW LEAVING STORAGE DURING INTERVAL
C
 1150   INTF = LIRC4*SRGX
        SRGX=SRGX+(RGX*PA)-INTF
         RU=RU + INTF
        SRGXT= SRGXT + (RGX*PA-INTF)
        RGXT=RGXT + INTF
C
C ***    OVERLAND PERVIOUS FLOW ROUTING ***
C
C
C RXB = VOLUME TO OVERLAND SURFACE DETENTION
C  ROSB = VOLUME OF OVERLAND FLOW TO STREAM
C  RESB = VOLUME OF OVERLAND Q REMAINING ON SURFACE
C
C
       F1= RXB-(RESB)
       F3= (RESB)+ RXB
```

```
         IF (RXB-(RESB)) 1170,1170,1160
    1160 DE= DEC*((F1)**0.6)
         GO TO 1180
    1170 DE= (F3)/2.0
    1180 IF (F3-(2.0*DE)) 1200,1200,1190
    1190 DE=(F3)/2.0
    1200 IF ((F3)-(.005)) 1210,1210,1220
    1210 ROSB= 0.0
         GO TO 1230
    1220    DUMV=(1.0+0.6*(F3/(2.0*DE))**3.)**1.67
         ROSB=(TIMFAC/60.)*SRC*((F3/2.)**1.67)*DUMV
         IF ((ROSB).GT.(.95*RXB)) ROSB=0.95*RXB
    1230 RESB= RXB-ROSB
            ROSB = ROSB*PA
           ROSINT = ROSB + INTF
C
C
C
C          * * *  UPPER ZONE DEPLETION * * *
C
C  DEEPL - DIFFERENCE IN UPPER AND LOWER ZONE RATIOS
C  PERCB - UPPER ZONE DEPLETION
C  PERC  - TOTAL U.Z. DEPLETION
C  INFLT  - TOTAL INFILTRATION
C  ROS   - TOTAL OVERLAND FLOW TO THE STREAM
C
            IF ((NUMI .EQ. 0).AND.(IMIN .EQ. 0))   GO TO 1240
            PERCB = 0.0
            GO TO 1280
C
    1240    DEEPL= ((UZSB/UZSN)-(LZS/LZSN))
            IF (DEEPL-.01)    1280,1280,1250
    1250     PERCB=0.1*INFIL*UZSN*(DEEPL**3)
C
         IF (SNOW .GT. 0) PERCB = PERCB*D4PX
C
             IF (UZSB - PERCB) 1260,1260,1270
    1260     PERCB = 0.0
             GO TO 1280
C
    1270     UZSB=UZSB-PERCB
             PERC=PERC+PERCB
             RUZB = RUZB - PERCB
    1280     INFL= P4-SHRD
              INFLT=INFLT + INFL
         RESS = RESS + RESB
          UZS= UZS + RUZB
         ROS = ROS + ROSB
         IF (UZS .LE. 0.0001) UZS=0.0
C
C END OF BLOCK LOOP
C
            RU=RU + ROS
           IF ((RESS).LT.(0.0001))  GO TO 1290
           GO TO 1300
```

```
      1290  LZS = LZS + RESS
            PESS = 0.0
            RESB = 0.0
      1300  IF (SRGXT.LT.(0.0001))  GO TO 1310
            GO TO 1320
      1310  LZS = LZS + SRGXT/PA
            SRGXT = 0.0
              SRGX = 0.0
C
C
C    * * * LOWER ZONE AND GROUNDWATER  * * *
C
C  SBAS  - BASE STREAMFLOW
C  SRCH  - SUM OF GRDWATER RECHARGE
C PREL - % OF INFILTRATION AND U.Z. DEPLETION ENTERING L.Z
C  F1A  - GROUNDWATER RECHARGE - IE. PORTION OF INFIL.
C         AND U.Z. DEPLETION ENTERING GRDWATER
C  K24L  - FRACTION OF F1A LOST TO DEEP GRDWATER
C
      1320      LZI=1.5*ABS((LZS/LZSN)-1.0)+1.0
                PREL=(1.0/(1.0+LZI))**LZI
                IF (LZS.LT.LZSN)  PREL=1.0-PREL*LNRAT
                F3= PREL*(INFLT)
                F1A = (1.0-PREL)*INFLT
                IF ((NUMI .EQ. 0).AND.(IMIN .EQ. 0))  GO TO 1330
                GO TO 1340
      1330      F3 = F3 + PREL*PERC
                F1A = F1A + (1.0-PREL)*PERC
      1340      LZS= LZS+F3
            F1= F1A*(1.0 - K24L)*PA
            GWF=SGW*LKK4*(1.0 + KV*GWS)
            SBAS= GWF
            RU=RU+GWF
            SPCH= F1A*K24L*PA
             SGW=SGW - GWF + F1
             GWS=GWS + F1
C
C   * * *       GROUNDWATER EVAP   * * *
C
C
C LOS  - EVAP LOST FROM GROUNDWATER
C
C     NOTE: EVAP FROM GRDWATER AND LZ IS CALCULATED ONLY DAILY
C
            IF ((HRFLAG.EQ.1).AND.(IHRR.EQ.21)) GO TO 1350
            GO TO 1430
      1350  IF (GWS .GT. 0.0001)  GWS = 0.97*GWS
            LOS= SGW*K24EL*REPIN*PA
            SGW=SGW - LOS
            GWS=GWS - LOS
            SNET= SNET + LOS
            REPIN= REPIN - LOS
            IF (GWS.LT.(0.0))  GWS=0.0
C
C  * * *       LOWER ZONE EVAP  * * *
```

```
C
C AETR - EVAP LOST FROM L.Z.
C
C
        IF (REPIN.LT.(0.0001))  GO TO 1420
        LNRAT = LZS/LZSN
         IF (K3-1.0)   1370,1360,1360
 1360    KF=50.0
         GO TO 1380
 1370    KF=0.25/(1.0-K3)
 1380    IF (REPIN - (KF*LNRAT))  1390,1400,1400
 1390    AETR= REPIN*(1.0-(REPIN/(2.0*KF*LNRAT)))
         GO TO 1410
 1400    AETR= 0.5*(KF*LNRAT)
 1410    IF (K3.LT.(0.50))  AETR=AETR*(2.0*K3)
         LZS=LZS - AETR
         SNET= SNET + PA*AETR
         ASNET = ASNET + LOS + PA*AETR
 1420    REPIN = 0.0
 1430    SNETI = SNET - SNET1
C
C
C
C WBAL - WATER BALANCE IN THE INTERVAL
C TWBAL - ACCUMULATED WATER BALANCE
C
C
 1440    WBAL = (LZS-LZS1+UZS-UZS1+RESS-RESS1)*PA+(SNET-SNET1+SGW-SGW1+
     X           SCEP-SCEP1+SRCH+SRGXT-SRGXT1+RU-PR)+(RESBI-RESBI1)*A
 1450    IF ((WBAL .LE. 0.0001).AND.(WBAL .GE. -0.0001))  WBAL = 0.0
        TWBAL=TWBAL+WBAL
C
       DPS = F1A*PA
       DPST = DPST + DPS
C
C
C                     RESETTING VARIABLES
C
       LZS1=LZS
       UZS1=UZS
       RESS1=RESS
       SCEP1=SCEP
       SRGXT1=SRGXT
       SGW1=SGW
       SNET1=SNET
       RESBI1=RESBI
        ASBAS = ASBAS + SBAS
        ASRCH = ASRCH + SRCH
       APR = APR + PRR
          ARU = ARU + RU
          ARUI = ARUI + RUI
          AROS = AROS + ROS
          ARGXT = ARGXT + RGXT
          IF ((NUMI.EQ.0).AND.(IMIN.EQ.0))  GO TO 1460
          GO TO 1470
```

```
      1460    AEPIN = AEPIN + EPIN1
              ASNET = ASNET + SNETI
      1470    AROSB = AROSB + ROSB
              AINTF = AINTF + INTF
              AROSIT = AROSIT + ROSINT
     C
      1480 CONTINUE
     C
     C
     C                      CUMULATIVE RECORDS
     C
           PRTOM = PRTOM + APR
           EPTOM = EPTOM + AEPIN
           RUTOM = RUTOM + ARU
           ROSTOM = ROSTOM + AROS
           RITOM = RITOM + ARUI
           RINTOM = RINTOM + ARGXT
           NEPTOM = NEPTOM + ASNET
           BASTOM = BASTOM + ASBAS
           RCHTOM = RCHTOM + ASRCH
     C
                ROBTOM = ROBTOM + AROSB
                ROBTOT = ROBTOT + AROSB
                INFTOM = INFTOM + AINTF
                INFTOT = INFTOT + AINTF
                ROITOM = ROITOM + AROSIT
                ROITOT = ROITOT + AROSIT
     C
           PRTOT = PRTOT + APR
           EPTOT = EPTOT + AEPIN
           RUTOT = RUTOT + ARU
           ROSTOT = ROSTOT + AROS
           RITOT = RITOT + ARUI
           RINTOT =RINTOT + ARGXT
           NEPTOT = NEPTOT + ASNET
           BASTOT = BASTOT + ASBAS
           RCHTOT = RCHTOT + ASRCH
     C
     C          LOGICAL VARIABLES LAST AND PREV ARE USED TO DETERMINE
     C          BEGINNING AND END OF EACH STORM. STORM BEGINS IF RU
     C          IS LESS THAN HYMIN IN ONE TIME INTERVAL, AND GREATER IN
     C          THE FOLLOWING ONE (PREV=.FALSE. , LAST=.TRUE.). STORM ENDS
     C          IF THE OPPOSIT OCCURS (PREV=.TRUE. , LAST=.FALSE.)
     C
           RUINCH=RU
           RU = (RU*AREA*43560.)/(TIMFAC*720.)
           IF ((RU.GE.HYMIN).AND.(TF.LE.2))  GO TO 1490
           LAST=.FALSE.
           GO TO 1570
      1490 LAST=.TRUE.
           IF (PREV) GO TO 1550
     C
     C          COUNT NUMBER OF STORMS AND RECORD TIME OF STORM BEGINNING
     C
           NOS=NOS+1
```

```
                IF (NOS.EQ.1) WRITE(6,4045)
                WRITE (6,4050) NOS,MNAM(IZ),MNAM(IX),YEAR
                STRBGN(1)=MNAM(IZ)
                STRBGN(2)=DAY
                STRBGN(3)=IHR
                STRBGN(4)=IMIN
        C
        C           INITIALIZATION OF VARIABLES FOR STORM SUMMARY
                NOSI=0
                TOTRUN=0.
                PEAKRU=0.
                ACSEDT=0.
                SEDMX=0.
                SEDTSC=0.
                SEDMXC=0.
                DO 1495 I=1,5
                ACPOLT(I)=0.
                PLTMX(I)=0.
                POLTSC(I)=0.
                PLTMXC(I)=0.
           1495 LMTS(I)=0
        C
        C            PRINT INITIAL CONDITION FOR A NEW STORM
        C
                IF (HYCAL.EQ.1) GO TO 1530
                WRITE (6,4060) WHT,ARUN
        C
        C            CALCULATE AND PRINT MEAN ACCUMULATION FOR (1) EACH
        C            LAND TYPE USE (WEIGHTED BY % OF PERVIOUS AND IMPERVIOUS
        C            AREAS), (2) THE ENTIRE WATERSHED AND THE TOTAL PERVIOUS
        C            AND IMPERVIOUS AREAS (WEIGHTED BY % OF VARIOUS LAND TYPE USE)
        C
                 TEM1=0.0
                 TEM2=0.0
                 TEM3=0.0
                 TEM4=0.0
                DO 1510 I=1,NLAND
                TEM=SRER(I)*(1-IMPK(I))+TS(I)*IMPK(I)
                WHFUN1=(AR(I)/AREA)*(1-IMPK(I))
                WHFUN2=(AR(I)/AREA)*IMPK(I)
                TEM1=TEM1+SRER(I)*WHFUN1
                TEM2=TEM2+TS(I)*WHFUN2
                TEM3=TEM3+WHFUN1
                TEM4=TEM4+WHFUN2
                IF (UNIT.GT.-1) GO TO 1500
                WRITE (6,4070) (LNDUSE(IK,I),IK=1,3),TEM,SRER(I),TS(I)
                GO TO 1510
           1500 TEM5=SRER(I)*2.24
                TEM6=TS(I)*2.24
                TEM=TEM*2.24
                WRITE (6,4070) (LNDUSE(IK,I),IK=1,3),TEM,TEM5,TEM6
                IF (LMTS(I).EQ.1) WRITE (6,4040)
           1510 CONTINUE
                IF (NLAND.EQ.1) GO TO 1530
                IF (TEM3.GT.0.0) TEM1=TEM1/TEM3
```

```
      IF (TEM3.LE.0.0) TEM1=0.0
      IF (TEM4.GT.0.0) TEM2=TEM2/TEM4
      IF (TEM4.LE.0.0) TEM2=0.0
      TEM=TEM1*(1-A)+TEM2*A
      IF (UNIT.LT.1) GO TO 1520
      TEM=TEM*2.24
      TEM1=TEM1*2.24
      TEM2=TEM2*2.24
 1520 WRITE (6,4080) TEM,TEM1,TEM2
 1530 CONTINUE
      WRITE (6,4090)
      IF (HYCAL.GT.1) GO TO 1540
      WRITE (6,4110) UFL
      GO TO 1550
 1540 WRITE (6,TIT)
      WRITE (6,4100) ((QUALIN(I,J),I=1,3),J=1,NQUAL)
      IF (UNIT.EQ.-1) GO TO 1545
 1545 WRITE (6,FORM) UFL,UTMP
 1550 QMETRC=RU*.0283
C
C                   PRINT DATE,TIME,AND FLOW
C
      WRITE (6,4130) MNAM(IZ),DAY,IHR,IMIN
      NOSI=NOSI+1
      FLOUT=RU
      IF (UNIT.GT.0) FLOUT=QMETRC
      WRITE (6,4120) FLOUT
      IF (HYCAL.NE.4) GO TO 1560
      RECOUT(2)=MNAM(IZ)
      RECOUT(3)=DAY
      RECOUT(4)=IHR
      RECOUT(5)=IMIN
 1560 IF (RU.GT.PEAKRU) PEAKRU=RU
      TOTRUN=TOTRUN+RUINCH
 1570 APR = 0.0
      AEPIN = 0.0
      ARU = 0.0
      ARUI = 0.0
      AROS = 0.0
      ARGXT = 0.0
      ASNET = 0.0
      ASBAS = 0.0
      ASRCH = 0.0
         AROSB = 0.0
         AINTF = 0.0
         AROSIT = 0.0
      IF (LAST.OR..NOT.PREV) GO TO 1640
C
C                    STORM SUMMARY
C
      IF (UNIT.LT.1) GO TO 1590
      TOTRUN=TOTRUN*25.4
      PEAKRU=PEAKRU*0.0283
      ACSEDT=ACSEDT*0.9072
      SEDMX=SEDMX*0.454
```

```
      DO 1580 I=1,NQUAL
      ACPOLT(I)=ACPOLT(I)*0.454
 1580 PLTMX(I)=PLTMX(I)*0.454
 1590 WRITE (6,4150)
      IF (HYCAL.EQ.4) WRITE (4,4150)
      WRITE (6,4140) NOS
      WRITE (6,4160) NOSI,(STRBGN(I),I=1,4),MNAM(IZ),DAY,IHR,
     *
     *                IMIN,DEPW,TOTRUN,UPL,PEAKRU
      IF (HYCAL.EQ.1) GO TO 1610
      WRITE (6,4170) ((QUALIN(I,J),I=1,3),J=1,NQUAL)
      WRITE (6,4180) WHT,ACSEDT,(ACPOLT(I),I=1,NQUAL)
      WRITE (6,4190) WHGT,SEDMX,(PLTMX(I),I=1,NQUAL)
      SEDTSC=SEDTSC/NOSI
      DO 1600 I=1,5
 1600 POLTSC(I)=POLTSC(I)/NOSI
      DO 1605 I=1,NQUAL
      DUM1(I)=POLTSC(I)/SCALEF(I)
 1605 DUM2(I)=PLTMXC(I)/SCALEF(I)
      WRITE (6,4200) SEDTSC,(DUM1(I),I=1,NQUAL)
      WRITE (6,4210) SEDMXC,(DUM2(I),I=1,NQUAL)
 1610 WRITE (6,4150)
C
C             ACCUMULATION FOR OVERALL STORM SUMMARY
C
      IF (HYCAL.NE.1) GO TO 1620
      STMCH(NOSY+NOS,1)=TOTRUN
      STMCH(NOSY+NOS,2)=PEAKRU
      GO TO 1640
 1620 IF (NOSY+NOS.GT.200) GO TO 1640
      STMCH(NOSY+NOS,1)=ACSEDT
      STMCH(NOSY+NOS,2)=SEDMX
      STMCH(NOSY+NOS,3)=SEDTSC
      STMCH(NOSY+NOS,4)=SEDMXC
      DO 1630 I=1,NQUAL
      KI=4*I
      STMCH(NOSY+NOS,KI+1)=ACPOLT(I)
      STMCH(NOSY+NOS,KI+2)=PLTMX(I)
      STMCH(NOSY+NOS,KI+3)=POLTSC(I)
      STMCH(NOSY+NOS,KI+4)=PLTMXC(I)
 1630 CONTINUE
      WRITE (6,4030)
 1640 CONTINUE
      PREV=LAST
C
C                     FORMAT STATEMENTS
C
 4030 FORMAT ('0')
 4040 FORMAT ('+',70X,'** LIMIT REACHED **')
 4045 FORMAT ('1')
 4050 FORMAT (3(/),130('*'),2(/),55X,'OUTPUT FOR STORM NO.',I3,
     1        ' - ',A4,A4,1X,I4)
 4060 FORMAT (//,1X,'ACCUMULATION OF DEPOSITS ON GROUND AT THE ',
     1        'BEGINNING OF STORM,',A4,'/',A4,
     2        /,3X,'LAND USE',8X,'WEIGHTED MEAN',9X,'PERVIOUS',8X,
```

```
     4         'IMPERVIOUS',/)
 4070 FORMAT (1X,3A4,9X,F7.3,2(12X,F7.3))
 4080 FORMAT (3X,'WEIGHTED MEAN',6X,F7.3,2(12X,F7.3))
 4090 FORMAT (//)
 4100 FORMAT (2X,'DATE    TIME   FLOW    TEMP  DO(PPM)   SEDIMENTS
     1         5(4X,3A4))
 4110 FORMAT ('  DATA    TIME   FLOW (',A4,')')
 4120 FORMAT ('+',14X,F8.3)
 4130 FORMAT (1X,A4,1X,I2,1X,I2,':',I2)
 4140 FORMAT (/,' SUMMARY FOR STORM # ',I3)
 4150 FORMAT (29('_'))
 4160 FORMAT (/,' NUMBER OF TIME INTERVALS',I4,/,
     1          ' STORM BEGINS',3X,A4,1X,I2,1X,I2,':',I2,/,
     2         ' STORM ENDS',5X,A4,1X,I2,1X,I2,':',I2,/,
     3         ' TOTAL FLOW (',A4,')',1X,F10.3,/,
     4          ' PEAK FLOW (',A4,')',2X,F10.3)
 4170 FORMAT (37X,' SEDIMENTS ',4X,5(4X,3A4))
 4180 FORMAT (' TOTAL WASHOFF (',A4,')',14X,F10.2,5X,5(F14.5,2X))
 4190 FORMAT (' MAX WASHOFF (',A4,'/15MIN)',10X,F10.2,5X,5(F14.5,2X))
 4200 FORMAT (' MEAN CONCENTRATION (GM/L)',9X,F10.2,5X,5(F14.5,2X))
 4210 FORMAT (' MAX CONCENTRATION (GM/L)',10X,F10.2,5X,5(F14.5,2X))
C
        RETURN
       END
       SUBROUTINE QUAL
C
C
       DIMENSION POLP(5,5),POLI(5,5),EIM(5),POLTLU(5,5),POLT(5),
     1           TSS(5),RER(5),ERSN(5),SER(5),TEMPX(24)
C
       COMMON /ALL/ RU,HYMIN,HYCAL,DPSI,UNIT,TIMFAC,LZS,AREA,RESB,SFLAG,
     1              RESB1,ROSB,SRGX,INTF,RGX,RUZB,UZSB,PERCB,RIB,P3,TF,
     2              KGPLB,LAST,PREV,TEMPX,IHR,IHRR,PR,RUI,A,PA,GWF,NOSY,
     3              SRER(5),TS(5),LNDUSE(3,5),AR(5),QUALIN(3,5),NOSI,NOS,
     4              NOSIM,UFL,UTMP,UNT1(2,2),UNT2(2,2),UNT3(2,2),WHGT,
     5              WHT,DEPW,ROSBI,RESBI,RESBI1,ARUN,LMTS(5),IMPK(5),
     6              NLAND,NQUAL,STMCH(200,24),RECOUT(5),FLOUT,SCALEF(5),
     7              SNOW,PACK,IPACK
C
       COMMON /QLS/ WSNAME(6),KRER,JRER,KSER,JSER,TEMPCF,COVMAT(5,12),
     1              KEIM,JEIM,NDSR,ARP(5),ARI(5),ACCP(5),ACCI(5),RPER(5),
     2              PMP(5,5),PMI(5,5),QSNOW,SNOWY,SEDTM,SEDTY,SEDTCA,
     3              ACPOLP(5,5),ACERSN(5),APOLP(5,5),AERSN(5),COVER(5),
     4              APOLI(5,5),ACEIM(5),AEIM(5),POLTM(5),POLTY(5),
     5              TEMPA,DOA,POLTCA(5),AERSNY(5),AEIMY(5),APOLPY(5,5),
     6              APOLIY(5,5),POLTC(5),PLTCAY(5),ACPOLI(5,5),RIMP(5)
C
       COMMON /STS/ ACPOLT(5),PLTMX(5),POLTSC(5),PLTMXC(5),
     1              ACSEDT,SEDMX,SEDTSC,SEDMXC,TOTRUN,PEAKRU
C
       DIMENSION LIMP(5),LIMI(5)
       REAL  JRER, KRER, JSER, KSER,KEIM,JEIM
       INTEGER HYCAL,TF,UNIT,LMTS ,RECOUT,SFLAG
C
       REAL*8 WSNAME
```

```
      DO 10 I=1,5
      LIMP(I)=.0
   10 LIMI(I)=.0
C
      IF (TF.GT.2) GO TO 250
      NOSIM=NOSIM+1
C
C          CONVERT ROSB - VOLUME OF OVERLAND FLOW REACHING STREAM -
C                         IN INCHES PER WHOLE WATERSHED TO INCHES
C                         PER PERVIOUS AREAS ONLY
C
      IF ((1.-A).GT.0.00001) GO TO 20
      ROSBQ=0.0
      GO TO 30
   20 ROSBQ=ROSB/(1.-A)
   30 CONTINUE
      DO 90 I=1,NLAND
C
C                    IF RAIN ON SNOW, INCREASE COVER BY % OF SNOW COVER
C
      IF (SNOW.EQ.0.OR.(PACK/IPACK).LT.COVER(I)) GO TO 35
      CR=COVER(I)+(1-COVER(I))*(PACK/IPACK)
      IF (CR.LT.COVER(I)) GO TO 35
      IF (CR.LE.1.0) COVER(I)=CR
   35 CONTINUE
C
C                              WASHOFF FROM PERVIOUS AREAS
C
      IF (SFLAG.EQ.1) GO TO 40
C
C                    IF SNOWS, BRANCH OVER FINES GENERATION
C
      RER(I)=(1-COVER(I))*KRER*PR**JRER
      SRER(I)=SRER(I)+RER(I)
   40 IF (RU.LE.0.0) GO TO 270
      IF((ROSBQ+RESB).GT.0.0) GO TO 60
      ERSN(I)=0.0
      DO 50 J=1,NQUAL
   50 POLP(I,J)=0.0
      GO TO 90
   60 SER(I)=KSER*(ROSBQ+RESB)**JSER
      IF(SER(I).LE.SRER(I)) GO TO 70
      SER(I)=SRER(I)
      LIMP(I)=1
   70 ERSN(I)=SER(I)*(ROSBQ/(ROSBQ+RESB))
      SRER(I)=SRER(I)-ERSN(I)
      FRSN(I)=ERSN(I)*ARP(I)
      IF(SRER(I).LT.0.0) SRER(I)=0.0
C
C      MONTHLY ACCUMULATION OF WASHOFF FROM PERVIOUS AREAS
C
      DO 80 J=1,NQUAL
      POLP(I,J)=ERSN(I)*(PMP(J,I)/100.)*2000.
      ACPOLP(I,J)=ACPOLP(I,J)+POLP(I,J)
   80 APOLP(I,J)=APOLP(I,J)+POLP(I,J)
```

```
      ACERSN(I)=ACERSN(I)+ERSN(I)
      AERSN(I)=AERSN(I)+ERSN(I)
   90 CONTINUE
C
C                                   WASHOFF FROM IMPERVIOUS AREAS
C
      DO 140 I=1,NLAND
      IF ((ROSBI+RESBI).GT.0.) GO TO 110
      EIM(I)=0.0
      DO 100 J=1,NQUAL
  100 POLI(I,J)=0.0
      GO TO 140
  110 TSS(I)=KEIM*((ROSBI+RESBI)**JEIM)
      IF (TSS(I).LE.TS(I)) GO TO 120
      TSS(I)=TS(I)
      LIMI(I)=1
  120 EIM(I)=TSS(I)*(ROSBI/(ROSBI+RESBI))
      TS(I)=TS(I)-EIM(I)
      EIM(I)=EIM(I)*ARI(I)
      DO 130 J=1,NQUAL
      POLI(I,J)=EIM(I)*(PMI(J,I)/100.)*2000.
      APOLI(I,J)=APOLI(I,J)+POLI(I,J)
  130 ACPOLI(I,J)=ACPOLI(I,J)+POLI(I,J)
      ACEIM(I)=ACEIM(I)+EIM(I)
      AEIM(I)=AEIM(I)+EIM(I)
  140 CONTINUE
C
C                                   STORMWATER TEMPERATURE AND DISSOLVED OXYGEN
C                                                     (ASCE,SE4(86),P41)
C
      TEMPC=(TEMPX(IHRR)*TEMPCF-32.)*5/9
      IF (TEMPC.LT.0.0) TEMPC=0.00
      DO=14.652-0.41022*TEMPC+0.007991*(TEMPC**2)-.000077774*(TEMPC**3)
C
C                                   WASHOFF SUMMARY FOR A GIVEN TIME INTERVAL
C
      DO 160 J=1,NQUAL
      POLT(J)=0.000
      DO 150 I=1,NLAND
      POLTLU(I,J)=POLP(I,J)+POLI(I,J)
      POLT(J)=POLT(J)+POLTLU(I,J)
  150 CONTINUE
      ACPOLT(J)=ACPOLT(J)+POLT(J)/2000.
      IF (POLT(J).GT.PLTMX(J)) PLTMX(J)=POLT(J)
      POLTC(J)=POLT(J)*454.*SCALEF(J)/(RU*TIMFAC*60.0*28.32)
      POLTSC(J)=POLTSC(J)+POLTC(J)
      IF (POLTC(J).GT.PLTMXC(J)) PLTMXC(J)=POLTC(J)
      POLTCA(J)=POLTCA(J)+POLTC(J)
  160 CONTINUE
      SEDT=0.000
      DO 170 I=1,NLAND
      SEDT=SEDT+ERSN(I)+EIM(I)
  170 CONTINUE
      ACSEDT=ACSEDT+SEDT
      SEDT=SEDT*2000.
```

```
      IF (SEDT.GT.SEDMX) SEDMX=SEDT
      SEDTC=SEDT*454./(RU*TIMFAC*60.0*28.32)
      SEDTSC=SEDTSC+SEDTC
      IF (SEDTC.GT.SEDMXC) SEDMXC=SEDTC
C
C                         PRINTING OF OUTPUT FOR ONE TIME INTERVAL
C
      TEMP=TEMPX(IHRR)*TEMPCF
      IF (TEMP.LT.32.0) TEMP=32.00
      DOA=DOA+DO
      TEMPA=TEMPA+TEMP
      SEDTCA=SEDTCA+SEDTC
      IF (RU.LT.HYMIN) GO TO 270
      IF(UNIT.EQ.-1) GO TO 190
      TEMP=TEMPC
      SEDT=SEDT*0.454
      DO 180 J=1,NQUAL
  180 POLT(J)=POLT(J)*0.454
  190 CONTINUE
      WRITE(6,4000) TEMP,DO,SEDT,SEDTC,(POLT(J),POLTC(J),J=1,NQUAL)
      IF (HYCAL.LT.4) GO TO 200
      WRITE(4,4100) (RECOUT(I),I=1,5),FLOUT,
     *              TEMP,DO,SEDT,SEDTC,(POLT(J),POLTC(J),J=1,NQUAL)
C
C           PRINT OF ADDITIONAL OUTPUT FOR CALIBRATION RUN
C
  200 IF ((SEDT.LE.0.001).OR.(HYCAL.GT.2)) GO TO 270
      RUI=(RUI*AREA*43560.)/(TIMFAC*720.)
      TEM=RU
      IF (UNIT.LT.1) GO TO 210
      TEM=TEM*0.0283
      RUI=RUI*0.0283
      PR=PR*25.4
  210 WRITE(6,4010) RU,UFL
      WRITE(6,4020) RUI,UFL
      WRITE (6,4030) PR,DEPW
      DO 240 I=1,NLAND
      ERSN(I)=ERSN(I)*2000.
      EIM(I)=EIM(I)*2000.
      TEM=ERSN(I)+EIM(I)
      IF (TEM.LE.0.001) GO TO 240
      IF (UNIT.LT.1) GO TO 230
      TEM=TEM*0.454
      EIM(I)=EIM(I)*0.454
      ERSN(I)=ERSN(I)*0.454
      DO 220 J=1,NQUAL
      POLTLU(I,J)=POLTLU(I,J)*0.454
      POLP(I,J)=POLP(I,J)*0.454
  220 POLI(I,J)=POLI(I,J)*0.454
  230 WRITE(6,4040) (LNDUSE(KK,I),KK=1,3),TEM,(POLTLU(I,J),J=1,NQUAL)
      IF (LIMP(I).EQ.0)
     *              WRITE(6,4050) COVER(I),ERSN(I),(POLP(I,J),J=1,NQUAL)
      IF (LIMP(I).EQ.1)
     *              WRITE(6,4060) COVER(I),ERSN(I),(POLP(I,J),J=1,NQUAL)
      IF (LIMI(I).EQ.0) WRITE(6,4070) EIM(I),(POLI(I,J),J=1,NQUAL)
```

```
          IF (LIMI(I).EQ.1) WRITE(6,4080) EIM(I),(POLI(I,J),J=1,NQUAL)
      240 CONTINUE
          WRITE (6,4090)
          GO TO 270
C
C             ACCUMULATION OF DEPOSITS DURING THE NO RAIN DAYS
C
      250 DO 260 I=1,NLAND
          TS(I)=TS(I)*(1.0-RIMP(I))+ACCI(I)
          SRER(I)=SRER(I)*(1.0-RPER(I))+ACCP(I)
          IF (RIMP(I).LE.0.0) GO TO 250
          TEM=ACCI(I)/RIMP(I)
          IF (TS(I).LT.TEM) GO TO 260
          TS(I)=TEM
          LMTS(I)=+1
      260 CONTINUE
      270 CONTINUE
C
     4000 FORMAT ('+',22X,F6.2,2X,F5.2,F9.2,F8.3,5(F8.2,F8.3))
     4010 FORMAT ('0',3X,'TOTAL FLOW',F8.3,', ',A4)
     4020 FORMAT (' ',1X,'IMPERV. FLOW',F8.3,', ',A4)
     4030 FORMAT (' PRECIPITATION ',F7.3,', ',A4)
     4040 FORMAT ('0',21X,3A4,1X,F10.2,8X,5(F10.3,6X))
     4050 FORMAT (' ',8X,'COVER=',F5.2,7X,'PERV.',3X,F10.2,8X,5(F10.3,6X))
     4060 FORMAT (9X,'COVER=',F5.2,7X,'PERV.',2X,'*',F10.2,8X,5(F10.3,6X))
     4070 FORMAT (27X,'IMPERV.',1X,F10.2,8X,5(F10.3,6X))
     4080 FORMAT (27X,'IMPERV.','*',F10.2,8X,5(F10.3,6X))
     4090 FORMAT (/)
     4100 FORMAT (I4,A4,1X,I2,1X,I2,':',I2,F8.3,F5.2,F5.2,F9.2,
         1           F8.3,5(F8.2,F8.3))
C
          RETURN
          END
/*
//LKED.SYSLMOD DD DSNAME=WYL.X2.A12.YJL.J7412.NO1,DISP=(NEW,KEEP),
//               SPACE=(TRK,(25,1,1),RLSE),UNIT=DISK,
//               VOL=SER=PUB003
//LKED.SYSIN DD *
    NAME  NPS
/*
```

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(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Development and initial testing of a mathematical model to continuously simulate pollutant contributions to stream channels from nonpoint sources is presented. The Nonpoint Source Pollutant Loading (NPS) Model is comprised of subprograms to represent the hydrologic response of a watershed, including snow accumulation and melt, and the processes of pollutant accumulation, generation, and washoff from the land surface. The simulation of nonpoint pollutants from both pervious and impervious areas is based on sediment as a pollutant indicator. The calculated sediment washoff is multiplied by user-specified 'potency factors' that indicate the pollutant strength of the sediment for each pollutant simulated. Both urban and rural areas can be simulated.

Initial testing of the NPS Model was performed on three urban watersheds in Durham, North Carolina; Madison, Wisconsin; and Seattle, Washington. The hydrologic simulation results were good while the simulation of nonpoint pollutants was fair to good. Sediment, BOD, and SS were the major pollutants investiaged. A detailed user manual is provided to assist potential users in application of the NPS Model. Parameter definitions and guidelines for parameter evaluation and calibration are included. Possible uses of the NPS Model for evaluation of nonpoint pollution problems are discussed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Simulation, Runoff, Hydrology, Erosion, Snowmelt, Water quality, Planning, Land use	Nonpoint pollution, Urban runoff, Model studies	2A 2B 8H 8L 8M 13B 20D

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